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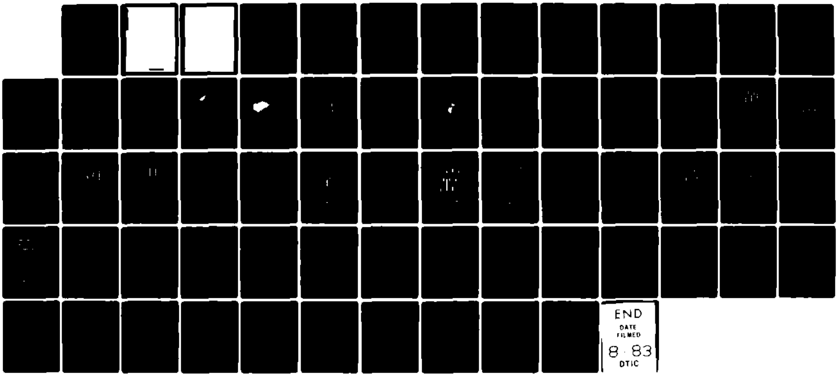

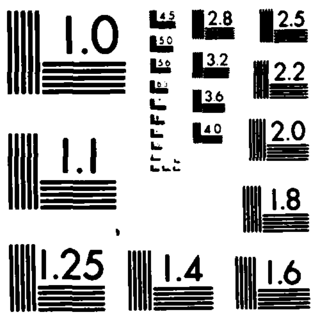

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The Savannah River below Lake Hartwell, Georgia-South Carolina, receives hypolimnetic water discharged from the reservoir for peak power generation. Invertebrates and particulate organic material (POM) in the water column were collected during a 24-hr release cycle at sites 1.0, 4.5, and 12.5 km downstream from the dam. Water released during generation reached a maximum discharge of 688 $m^3 sec^{-1}$. River discharge was less that 10 $m^3 sec^{-1}$ during nongeneration periods.

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20. ABSTRACT (Continued).

Highest POM concentrations were associated with the initial downstream surge of water at the start of power generation; values were 200 to 400 times greater than those during nongeneration periods. POM concentrations rapidly decreased to less than one tenth of the initial surge levels during high flow. Much of the POM originated in the tailwater, and concentrations increased at successive downstream sites.

Of the drifting invertebrates, 80 to 93 percent originated in the reservoir; the rest, primarily Oligochaeta, Diptera, and Ephemeroptera, were from the tailwater. Densities of benthic invertebrates were highest during passage of the initial release surge, whereas densities of invertebrates originating in the reservoir peaked 2 to 3 hr after the initial surge at each station, during maximum release. Densities of drifting benthic organisms decreased rapidly after the initial surge and increased with increasing distance downstream.

PREFACE

This study is part of the Environmental and Water Quality Operational Studies (EWQOS) Program, Task IIB, Reservoir Releases. The EWQOS Program is sponsored by the Office, Chief of Engineers, and is assigned to the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss, under the direction of the Environmental Laboratory (EL).

This report was written by Dr. William Matter, University of Arizona, Tucson; Mr. Patrick Hudson, Southeast Reservoir Investigations, National Reservoir Research Program, U. S. Fish and Wildlife Service, Clemson, S. C.; and Drs. John Nestler and Gary Saul, EL, WES.

Preparation of this report was under the direct supervision of Dr. Nestler and the general supervision of Mr. Aaron Stein, Acting Chief, Water Quality Modeling Group, EL; Mr. Donald L. Robey, Chief, Ecosystem Research and Simulation Division, EL; and Dr. John Harrison, Chief EL. Dr. Jerome L. Mahloch was the Program Manager of EWQOS.

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MOVEMENT, TRANSPORT, AND SCOUR OF PARTICULATE ORGANIC MATTER AND AQUATIC INVERTEBRATES DOWNSTREAM FROM A PEAKING HYDROPOWER PROJECT

PART I: INTRODUCTION

Problem

1. Considerable attention has been focused on hydropower projects as a relatively pollution-free means of generating electricity. Peaking power generation at large reservoirs is particularly attractive since these projects can efficiently increase power production with increasing demand for electricity.

2. Although peaking power projects do not emit the pollutants associated with gas-fired, coal-fired, and nuclear power plants, hydropower facilities can have severe environmental impacts on downstream reaches (INTASA 1980). The release of stored water to meet demands for peaking power may result in severe flow fluctuations (Figure 1) in the tailwater. The high flows associated with peaking power generation may be similar in magnitude to naturally occurring floods that scour benthos from the streambed in unregulated streams and sweep them downstream as part of the drift (Anderson and Lehmkuhl 1968; Bishop and Hynes 1969; Hoopes 1974; Siegfried and Knight 1977). Periods of rapidly falling water levels during decreased power demand may strand many stream organisms. The zone of fluctuation created by alternate high and low flows is not readily colonized by benthic invertebrates (Fisher and LaVoy 1972). Peaking releases may also interfere with invertebrate recolonization of denuded areas by preventing successful oviposition by adults or by scouring away organisms that drift, crawl, or swim in from other areas.

3. Chemical and physical characteristics of impounded water may differ from those occurring naturally in the stream prior to impoundment (Baxter 1977). Water quality of reservoir releases may exceed the tolerance levels of aquatic biota or interrupt the normal progression

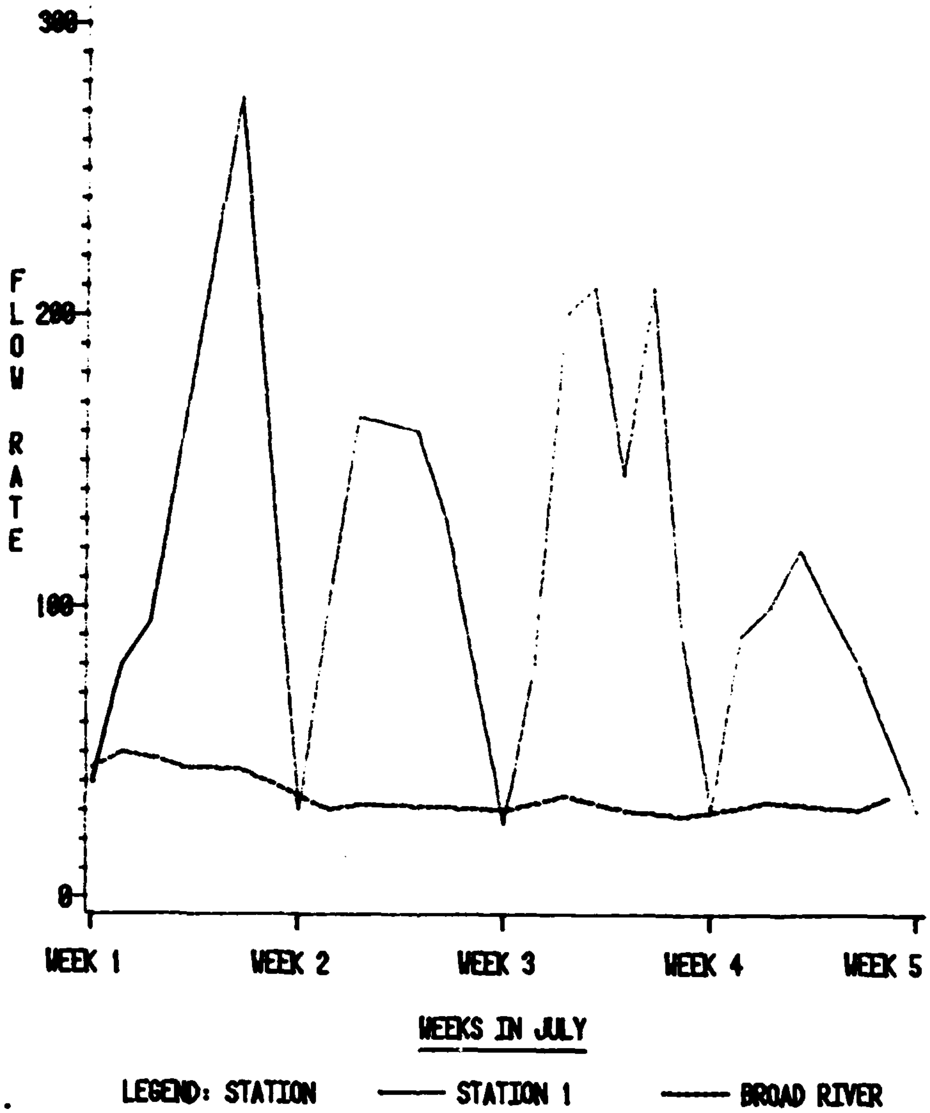


Figure 1. Comparison of representative mean daily flows (m^3 sec^{-1}) for the Lake Hartwell tailwater representative and the Broad River of Georgia. The two sites are at the same elevation and approximately 160 km apart. Note the reduced weekend releases and increased weekday releases reflecting demand for peaking power (data from Dudley and Golden 1974)

of life history stages by delaying or inhibiting temperature-mediated events such as spawning of fish and emergence of aquatic insects. Figure 2 displays the pronounced temperature changes that can occur during the week in the tailwater of a peaking hydropower project because of summertime warming of coldwater releases. Additionally, deep releases from the stratified reservoir may have low oxygen concentrations and contain high levels of reduced substances. Ultimately, the composition and abundance of aquatic biota of the tailwater ecosystem may be considerably modified from that of unregulated streams in the same geographical area (Ward and Stanford 1979).

4. Achieving downstream environmental quality objectives consistent with peaking power operation requires detailed information on the tailwater ecosystem. This information is not generally available for most projects. The problem is further complicated by inadequate documentation of the environmental requirements of many tailwater organisms.

Study Approach

5. This report describes the effects of daily peaking power releases on the tailwater ecosystem downstream from Lake Hartwell on the Georgia-South Carolina border. This hydropower project, like most peaking power facilities, discharges deep releases. Consequently, the impacts of water quality and temperature alterations are not considered separately from the impacts of flow alterations resulting from power generation. The field investigation detailed in this report focuses on benthic organisms, particularly immature insects, since they are probably the best single biotic index for evaluating environmental impacts on lotic systems. Due to their limited mobility and relatively long life span, they reflect many characteristics of their habitat including water quality, water quantity, substrate factors, availability of food, and predators. The benthos are also important secondary producers in lotic systems, converting autochthonous and allochthonous materials into benthic biomass available to higher members of the food chain.

6. Altered flows (Figure 1) and modified water quality caused by

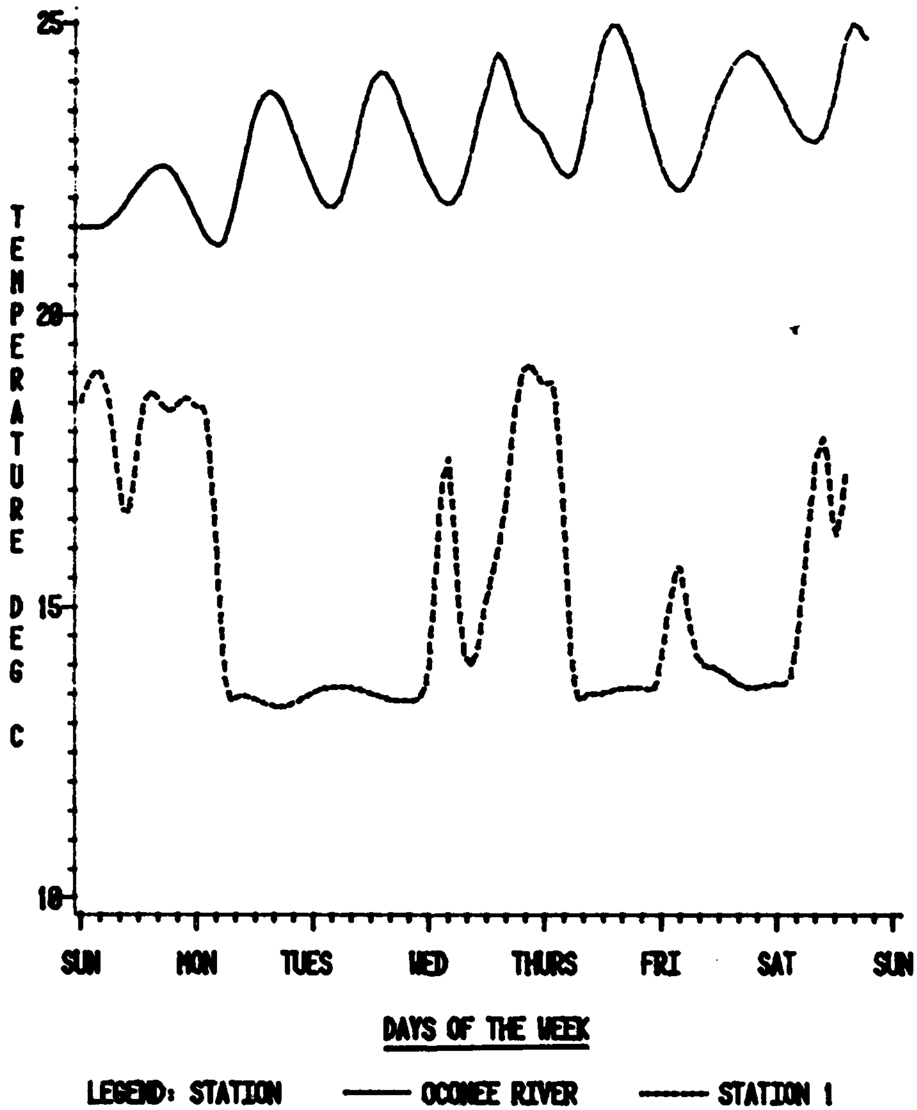


Figure 2. Comparison of temperature fluctuations in July 1972 in the Oconee River, Georgia, with temperatures immediately downstream from Lake Hartwell. Note the depression of water temperatures caused by deep releases during weekday power generation and the rise in temperatures associated with weekend or nongeneration periods (data from Dudley and Golden 1974)

reservoir operation may impact the transport and type of food organisms available to benthic organisms. An important source of food for benthos in small to medium unregulated streams is particulate organic matter (POM) such as leaves, bark, and other organic detritus washed in from the watershed (Webster, Benfield, and Cairns 1979). This material is largely unavailable immediately below a dam since most of it settles within the reservoir. Periphyton and macrophytes are important food sources in medium to large unregulated streams. High flows resulting from peaking power generation may scour streamside litterfall, macrophytes and periphyton, thus removing major food sources of stream benthos. Other types of POM, not normally of importance in many unregulated streams, may be available to benthos in tailwaters. Reservoir releases may contain living, moribund, and dead phytoplankton, zooplankton, aquatic insects, and fish with associated bacteria and fungi. Additionally, clear, nutrient-rich releases may foster the luxuriant growth of attached algae, thus providing an additional source of food for tailwater organisms (Walburg et al. 1981).

7. In light of the above discussion of potential impacts on the tailwater benthos, this report has the following objectives:

- a. Relate the effects of peaking power generation on the magnitude, composition, and periodicity of invertebrate drift during a 24-hr weekday peaking power generation and during low flow periods (weekends).
- b. Assess the relative significance of drift losses by comparing drift to the density and composition of benthic organisms.
- c. Investigate the colonizing rate of invertebrates in the tailwater to determine if peaking power generation adversely affects the ability of the benthic community to recolonize available habitats.
- d. Gain a better understanding of the foods available to benthic organisms by describing the origin, composition, abundance, and movement of POM, and the composition and abundance of periphyton and macrophytes in the tailwater ecosystem.

This information can be used to identify operational alternatives that minimize detrimental effects of peaking hydropower operation on reservoir tailwaters, thus maintaining or enhancing downstream environmental quality.

PART II: MATERIALS AND METHODS

Study Site

8. Lake Hartwell is a 22,390-ha, multipurpose reservoir with a volume of 3.51×10^9 m^3, situated on the Savannah River between Georgia and South Carolina. The lake has a maximum depth of 56 m and thermally stratifies during the summer with the thermocline located at a depth of about 8.0 m (Dudley and Golden 1974). Four 66,000-kW generators draw reservoir water through 7.3-m-diam penstocks located at a center-line depth of 30.0 m at full pool elevation of 201 m above mean sea level.

9. The Lake Hartwell project was selected as a study site because it is representative of many peaking hydropower facilities. Water is released primarily for electrical generation during weekday peak power demand (about 1200-2100 hours in the summertime and 0600-0900 and 1700-2000 hours in the fall, winter, and spring). The timing and quantity of releases from a peaking power project differ considerably from flows in unregulated rivers in the same geographical area (Figure 1). Maximum weekday peaking power flows at Lake Hartwell are about 700 m^3 sec^{-1} and cause the water level to rise approximately 2 m immediately downstream from the dam. Flows from a weekend "fish release" (a low flow release that maintains low water temperatures for the trout fishery) normally average about 100 m^3 sec^{-1} for a period of about 1-3 hr (Figure 3). Minimum flows during nongeneration periods, including tributary input and seepage, are estimated to be 3-10 m^3 sec^{-1}. Hypolimnetic water released into the tailwater seldom exceeds a temperature of 16°C, thus providing temperatures suitable for survival of stocked trout. In the warmer months temperature and dissolved oxygen are often higher in the tailwater during nongeneration periods than in the water released from the reservoir. Reservoir releases can expose tailwater organisms to diel changes in water quality (Figure 4). These changes may be especially pronounced at the start of weekday generation after a weekend of no release. Additionally, the releases may contain reduced

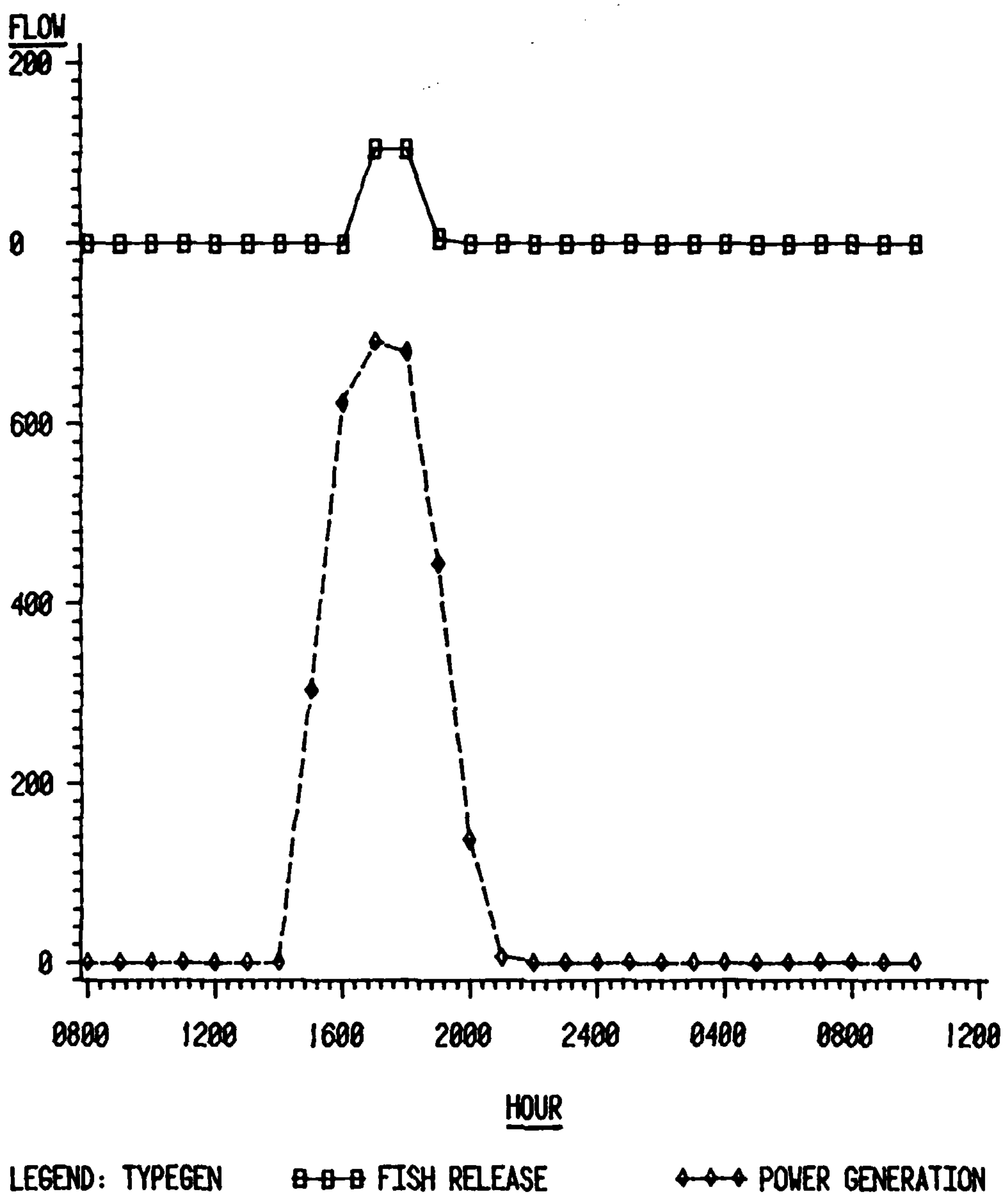


Figure 3. Comparison of mean hourly flows ($m^3\ sec^{-1}$) during the weekend low flow release (upper graph) and the weekday power generation cycle (lower graph) in the Lake Hartwell tailwater during the study

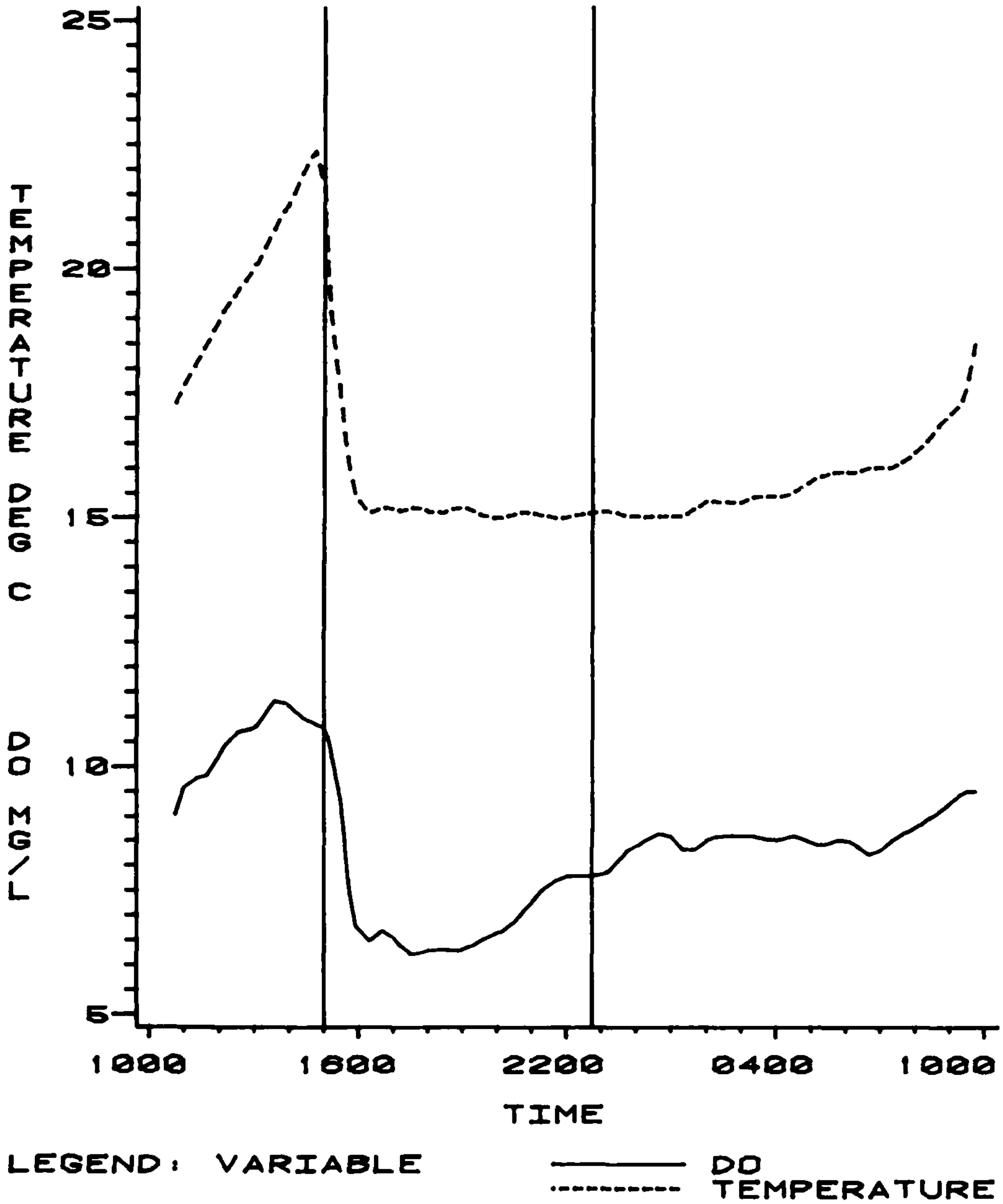


Figure 4. Changes in temperature and dissolved oxygen at station 2 during this study. The vertical reference lines indicate the passage of the initial surge (1500 hr) and the end of generation (2245 hr). Note the decrease in temperature and DO at the beginning of generation and the gradual increase of these parameters during nongeneration

compounds produced in the hypolimnion during reservoir stratification (Walburg et al. 1983).

10. The high flows associated with power production have caused extensive armoring of the streambed. Within the first kilometre below the Hartwell Dam, the tailwater substrate is predominantly large boulders and bedrock, interspersed with cobble and coarse gravel. Deposition of fine particle materials is restricted to streambanks and localized slackwater areas. Fine particle deposition becomes more common downstream; however, gravel and cobble predominate at least 13 km downstream from the project.

11. Sampling stations were selected 1.0, 4.5, and 12.5 km downstream from the dam (stations 1, 2, and 3, respectively). A map of the sampling stations can be found in Figure 5.

Sampling Methods

Invertebrate studies

12. The first portion of this study investigated the dynamics and significance of invertebrate drift by describing the movement, composition, and periodicity of drift and comparing drift totals to total benthic invertebrate biomass. In addition, studies of benthos colonizing rates were conducted to determine if peaking power operation interfered with benthic invertebrate recolonization of disturbed or denuded areas.

13. Drift studies. Rectangular drift nets, 15 cm by 15 cm at the mouth and 145 cm long, were used to estimate import of large reservoir zooplankton and transport of benthic invertebrates under different flow conditions during both a weekday peaking power generation cycle and a weekend "fish release." The nets were constructed of 450-μm mesh nylon net secured to a brass rod frame and held in the water column (about 8 cm off the bottom) by steel rods anchored in a concrete block (Figure 6). The relatively large mesh size was used to minimize net clogging. The timing of transport of small (<450 μm) zooplankton not retained by the net was probably quite similar to that of larger

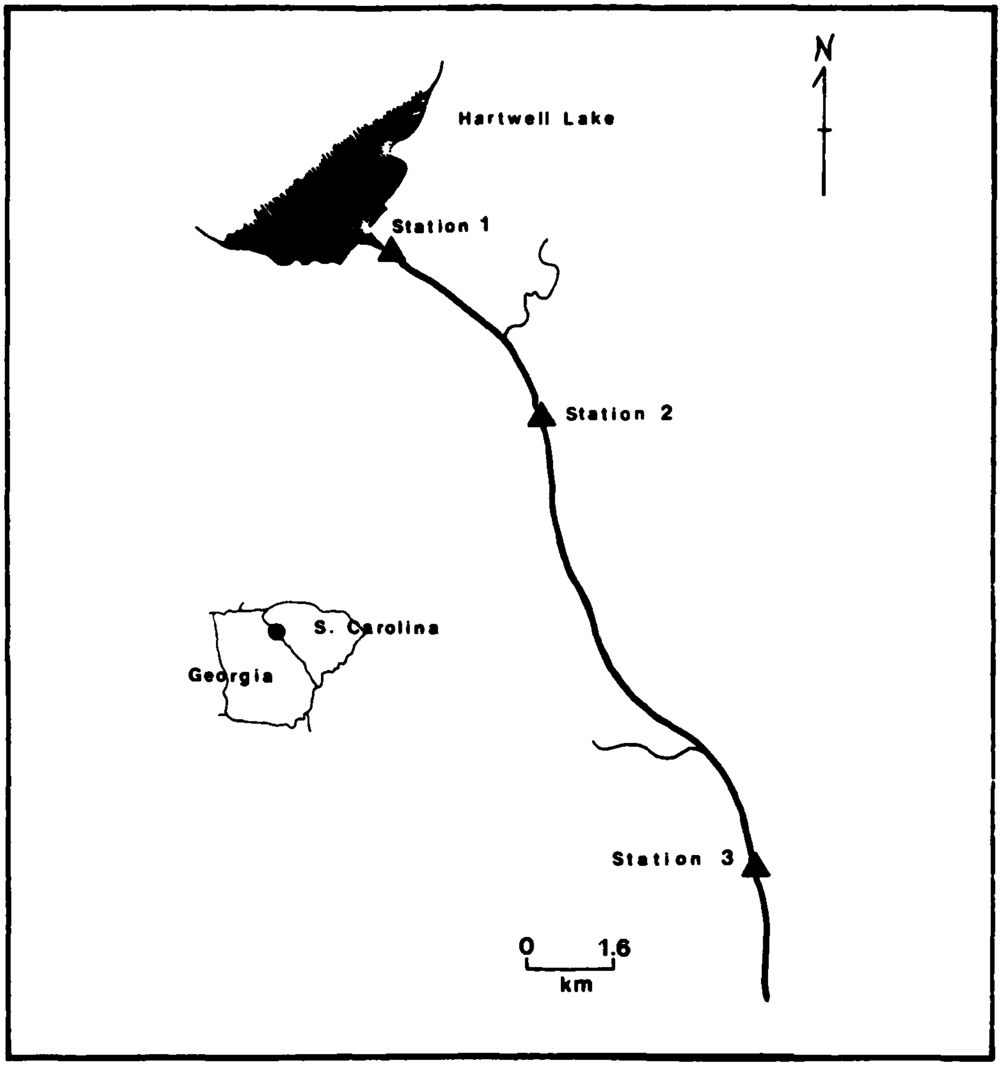


Figure 5. Hartwell Lake and location of tailwater sampling stations (Walburg et al. 1983)

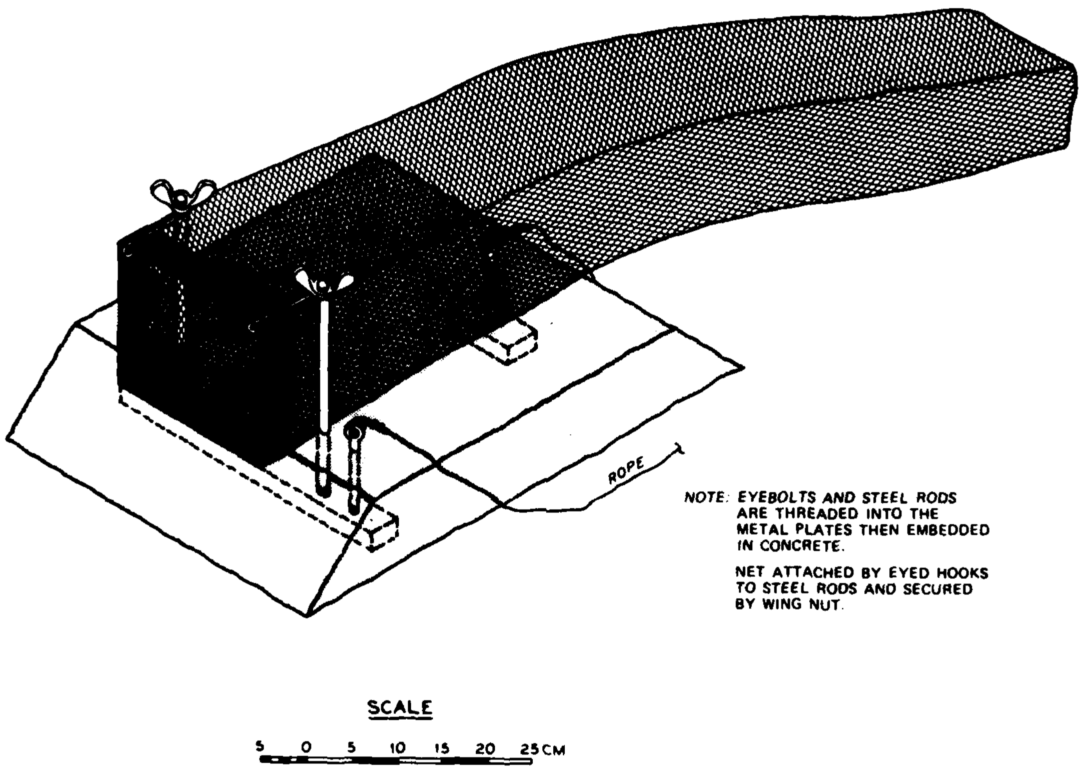


Figure 6. Drift net used to estimate invertebrate movement and POM transport in the Lake Hartwell tailwater

zooplankton. During peaking flows, an additional net of identical design was held just below the water surface by a boat-mounted or hand-held frame at each station and left in position over the same time period as the lower net to permit calculation of a mean concentration of POM and invertebrates in the water column since density may change with depth (Matter 1975). Nets were set within 5 m of the riverbank to facilitate access during high flows. Drift samples were taken during a generation cycle at stations 1, 2, and 3 between 0900 hours on 12 July 1979 and 0930 on 13 July 1979 (Figure 7). Drift samples during the weekend

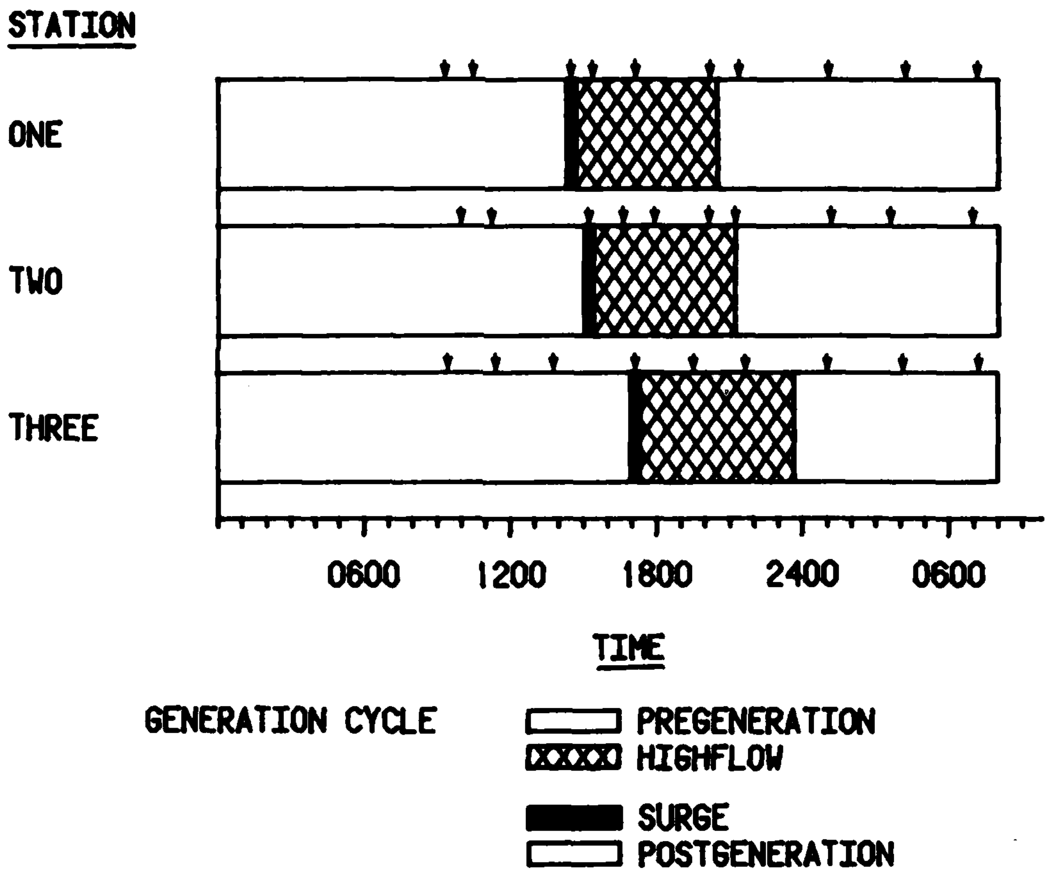


Figure 7. Schematic representation of the downstream movement of the surge and high flows at each station during a generation cycle from 12-13 July 1979. The arrows above each bar indicate the times that drift nets were set out. Flows associated with power generation are progressively delayed and lengthened as the water moves downstream

release were taken only at station 2 for 24 hr beginning at 0730 hours 21 July 1979. During the weekend study, one drift net was set on each side of the channel. One additional net was set over the entire duration of the low flow release. Current velocities were estimated immediately adjacent to the drift nets with a Price AA current meter.

14. Nets at each station were recovered after 20-30 min during the generation cycle and after 3-4 hr during the weekend release to minimize net clogging and subsequent backwashing. Collected material was preserved in 10 percent formalin and returned to the laboratory for sorting, identification, enumeration, drying, and weighing.

15. Drift data from the peaking power generation cycle were consolidated into the following four distinct hydraulic regimes:

a. PREGENERATION - period before power generation begins.

b. SURGE - initial 20 min of peaking operation.

c. HIGH FLOW - period of peaking power generation excluding the surge.

d. POSTGENERATION - period after power generation.

Nighttime drift was sampled during the postgeneration period to separate behavorial drift from flow-induced drift.

16. The volume of water filtered by each net was used to calculate the density of invertebrates in the water column. An estimate of total invertebrate drift through the entire tailwater cross section at each station over 24 hr was calculated following the conventions of Matter, Hudson, and Saul (1982):

$$D = \sum_{i=1}^{4} d_i v_i \tag{1}$$

where

D = total drift

i = one of four flow conditions (i.e. pregeneration, surge, etc.)

d = mean density of invertebrates (number/m^3 or mg/m^3) during the i^{th} flow condition

v = total volume of stream water passing through the cross section during the i^{th} period.

17. Colonization studies. Artificial substrates were constructed of large-sized gravel and stone embedded in concrete (Figure 8). These artificial substrates were generally heavy enough to resist movement during the high flows associated with peaking power generation and sufficiently unobtrusive to minimize damage by vandalism. The surfaces of the blocks were wetted and scrubbed with a wire brush prior to final hardening of the concrete in order to expose stones and to generally roughen the blocks, making them more similar to natural substrates. On 26 June 1979, 15 artificial substrate samplers were placed near each of the drift stations. Natural substrates and nongeneration flow

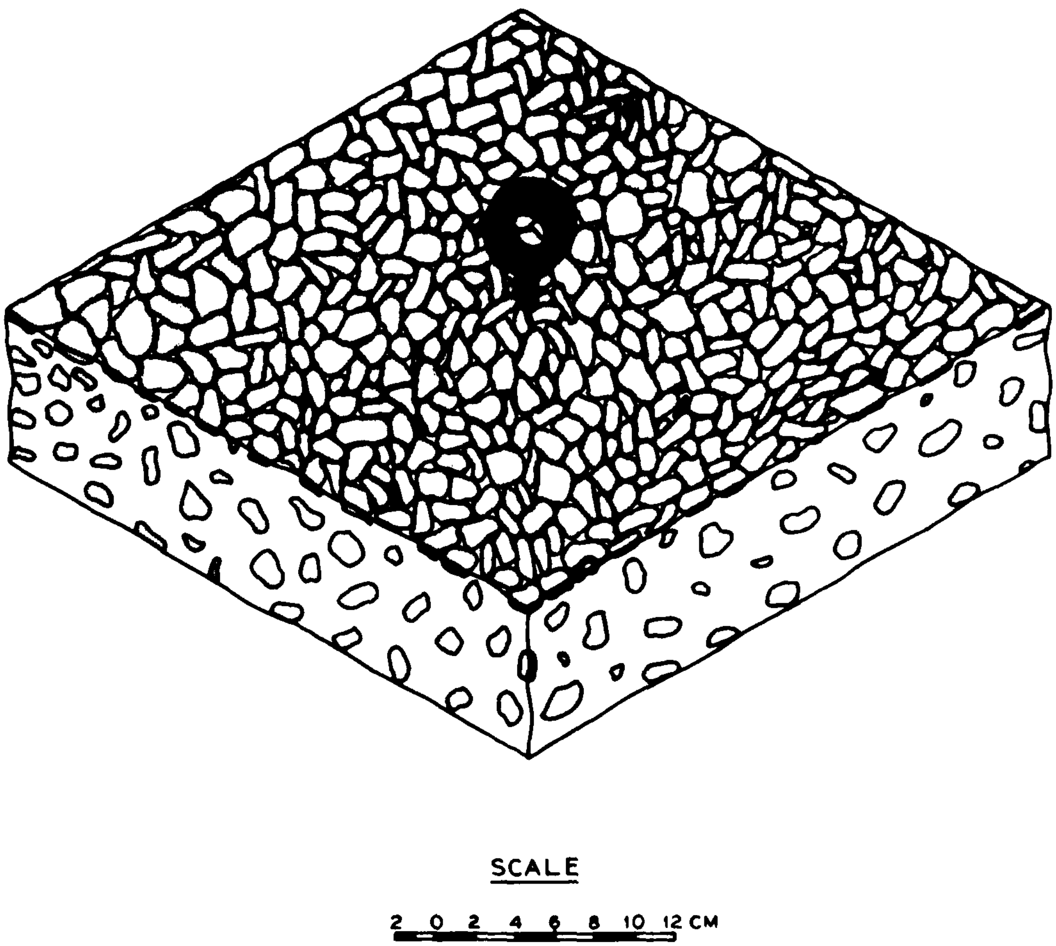


Figure 8. Artificial substrate used during the colonization study

conditions at each of the colonization sites were generally similar. Four substrates from each station were recovered after 12 days exposure (several of the substrates were either removed or swept downstream) and five substrates were removed at the end of the 19- and 26-day intervals.

18. A net was placed downstream from each substrate to capture organisms dislodged during the recovery process. The colonized substrates were then placed in a large metal tub and submerged in a solution of isopropyl alcohol-water-hydrochloric acid. This mixture caused the benthos to release their attachment from the substrate (Britt 1955). After several minutes in the cleaning solution, the blocks were lightly rubbed by hand and then more vigorously scrubbed with a nylon brush to remove all attached invertebrates. The organisms were removed from the solution by filtration through a 420-μm mesh screen, preserved in 10 percent formalin, and processed in much the same manner as the drift samples.

Particulate organic matter transport

19. This portion of the study quantified the movement and standing crop of organic matter in the tailwater. POM >450 μm was collected during the same net sets used to collect drift samples. The POM was separated from the invertebrates by manual sorting and sieving through screens in water. Smaller size classes of POM were collected with a grab sampler and then passed through sieves. The various POM fractions (<80 μm, >80 μm and <450 μm, and >450 μm) were washed onto preashed, tared glass fiber filters and dried for 24 hr at 60°C prior to dry weight determination. Filters were then ignited at 505°C for 15 min and reweighed to determine ash-free dry weights (AFDW). Benthic POM samples were collected in conjunction with periphyton samples (described in paragraph 24).

Chlorophyll studies

20. Phytoplankton and much of the periphyton that may be potentially scoured off the streambed are too small to be collected in drift nets. Therefore, the import of reservoir phytoplankton and the periodicity of periphyton scour was estimated by measuring chlorophyll-a concentrations both in the reservoir and over a generation cycle in

the same three tailwater stations used for the drift studies. All water samples for chlorophyll-a analyses were collected during the daylight hours of 12 July 1979. Duplicate 2- to 3-ℓ samples were collected at 20, 30, and 40 m in the reservoir prior to generation. These depths straddle the intake port centered at a depth of 30 m. Samples were filtered through an 80-μm mesh screen to remove zooplankton and then filtered through a Gelman A/E glass fiber filter, treated with 0.2 ml magnesium carbonate suspension (American Public Health Association (APHA) 1976), transported to the laboratory on ice in darkened containers, and frozen. Monochromatic spectrophotometric determination of chlorophyll-a with correction for pheophytin (APHA 1976) was conducted within 24 hr after freezing. Optical densities were measured with a Perkin Elmer Model 111 UV-VIS spectrophotometer using 1-cm cuvettes.

21. Duplicate 20-ℓ samples were taken at each tailwater site prior to generation, during the surge, and about 1 hr after maximum releases. The samples were passed through a 420-μm mesh screen to eliminate large macrophyte particles and then through an 80-μm mesh screen. Material retained by the 420-μm mesh sieve was discarded since macrophytes and mats of filamentous algae exhibit a patchy distribution in the water column inadequately characterized by a 20-ℓ sample. Separation of the remaining particles into those greater than and less than 80 μm was conducted since most, if not all, particles in the reservoir were in the smaller size fraction, while tailwater contributions were in both size fractions. Particles retained on the 80-μm screen were washed onto a glass fiber filter and treated as above. Two-litre samples of the filtrate were filtered through glass fiber filters and treated as above. Results from both size fractions are presented as milligrams chlorophyll-a per litre.

Survey of attached plants

22. A preliminary survey on 3 June 1979 was conducted to identify common tailwater plant taxa and, if possible, to associate dominant groups with specific areas or conditions within the tailwater. An extensive survey was conducted on 17 November 1979 to quantify the abundance and distribution of attached plants. The 17 November sample

was generally similar to the 3 June sample and was considered, therefore, to be representative of the summer-fall plant community in the tailwater.

23. The 3 June survey was conducted at the stations used for the drift studies and also at the mouth of Generostee Creek between stations 1 and 2. Periphyton samples were scraped from rocks and immediately placed in M-3 preservative (Meyer 1971). Macrophytes were collected intact and refrigerated until identification and washing for removal of epiphytes. Diatom specimens were prepared using an acid-dichromate cleaning technique (Patrick and Reimer 1966) to remove fouling organic matter, mounted in Naphrax diatom mountant, and examined at 1250X using obliqued bright-field illumination. Algal epiphytes were preserved as voucher specimens and later identified under phase microscopy.

24. On 17 November 1979, four quantitative periphyton samples were collected during nongeneration at each of the stations used in the drift study. A device similar to that developed by Stockner and Armstrong (1971) covering an area of 22.9 cm was used to collect the periphyton samples. The samples were then stored under refrigeration until analysis began on the next day. Each sample was brought to a total volume of 1 ℓ in a graduated cylinder. Measured aliquots were taken for determination of pigment composition, dry weight, ash-free dry weight, and relative species composition. Aliquots for species determination were preserved using M-3 preservative (Meyer 1971). Duplicate aliquots were extracted and analyzed for chlorophyll-a and pheophytin by the pheophytin correction method (APHA 1976). Single aliquots were filtered onto precombusted, preweighed glass fiber filters and analyzed for dry weight and ash-free dry weight according to standard techniques (APHA 1976). Data obtained from these analyses were normalized according to the volume of the aliquots and reported on an areal basis. Proportioned counts were made using a Palmer nannoplankton chamber for green and blue-green algae and diatom mounts for the diatom species.

PART III: RESULTS

Invertebrate Studies

Drift studies during power generation

25. Analysis of the drift data indicates that flow changes resulting from peaking power operation affect the magnitude, timing, and composition of invertebrate drift in the Lake Hartwell tailwater. Drift density (number per cubic metre) is greatest during high flow and initial surge of water associated with power generation, but the origin of invertebrates changes between these two time periods. During the surge, drift density is dominated by benthos originating from within the tailwater; but during high flow, drift density is dominated by reservoir invertebrates predominantly *Chaoborus* and zooplankton (Figure 9). Note also that during nongeneration the density of reservoir plankton decreases with distance from the project whereas the density of reservoir and tailwater forms increase during high flow.

26. A variety of benthic invertebrates was represented in the drift (Table 1). The relative abundance of major taxa in the benthic drift changed with alterations in the hydrograph (Figure 10). Oligochaeta made up very little of the drift during the pregeneration and postgeneration periods, but represented 50 to 65 percent of the drift during the surge and subsequent high flow period. Ephemeroptera (mayflies) made up 45 to 85 percent of the benthic drift during pregeneration and postgeneration, but represented a smaller proportion of the drift during the surge and high flow periods. However, the abundance of mayflies increased downstream during the surge period. Diptera generally represented 30 to 40 percent of the drift in all time periods but tended to be relatively less abundant in postgeneration samples. Only Ephemeroptera exhibited a definite increase in drift density during the night.

27. Total drift, both as numbers and weight, is obtained by multiplying drift density by release volume at each station for each portion of the generation cycle. Total estimated 24-hr drift by station ranged

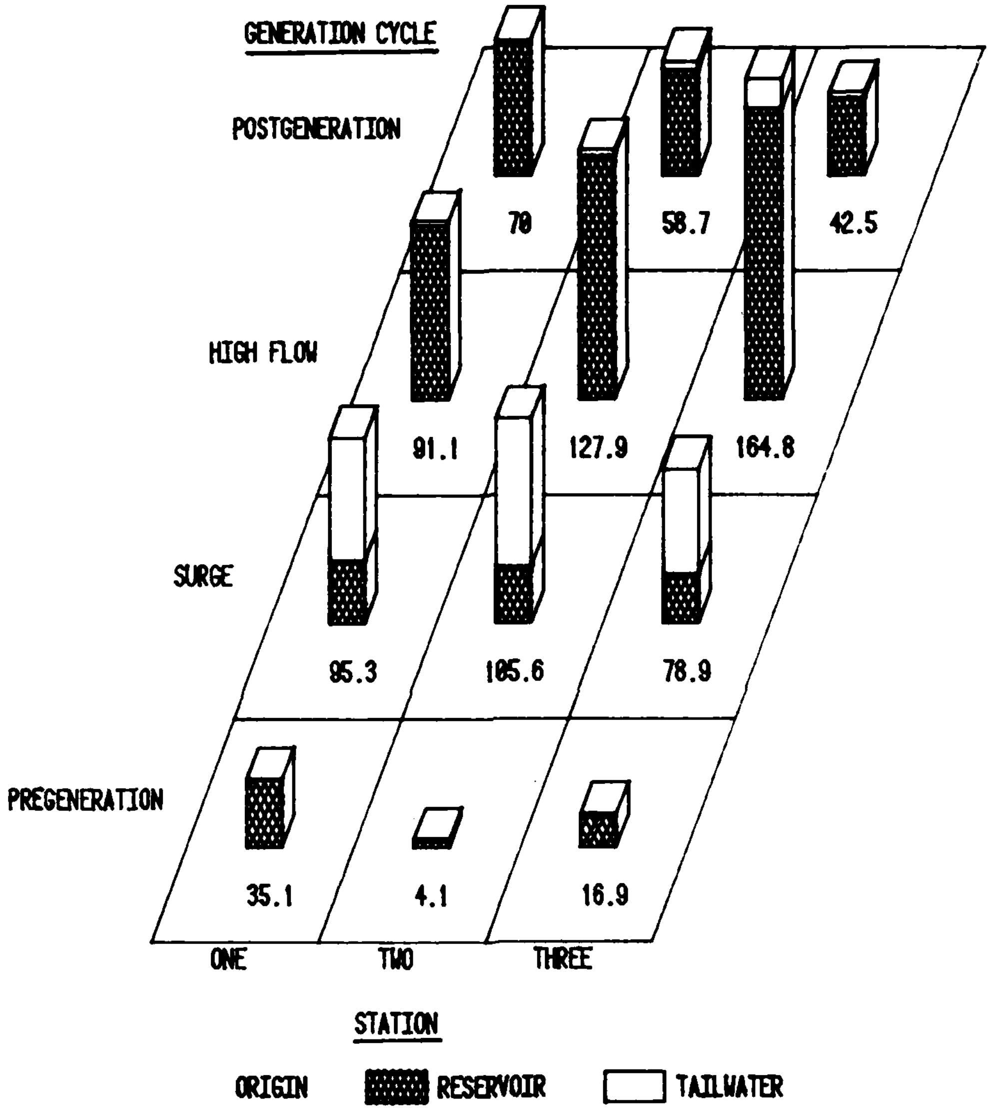


Figure 9. Estimated densities (number m^{-3}) of invertebrates originating from the reservoir (primarily zooplankton and *Chaoborus*) and tailwater (primarily Oligochaeta, Chironomidae, and Ephemeroptera) over a generation cycle. Note the increased density of tailwater benthos during the surge period and the gradual depletion of reservoir invertebrates from station 1 to station 3 during the postgeneration period

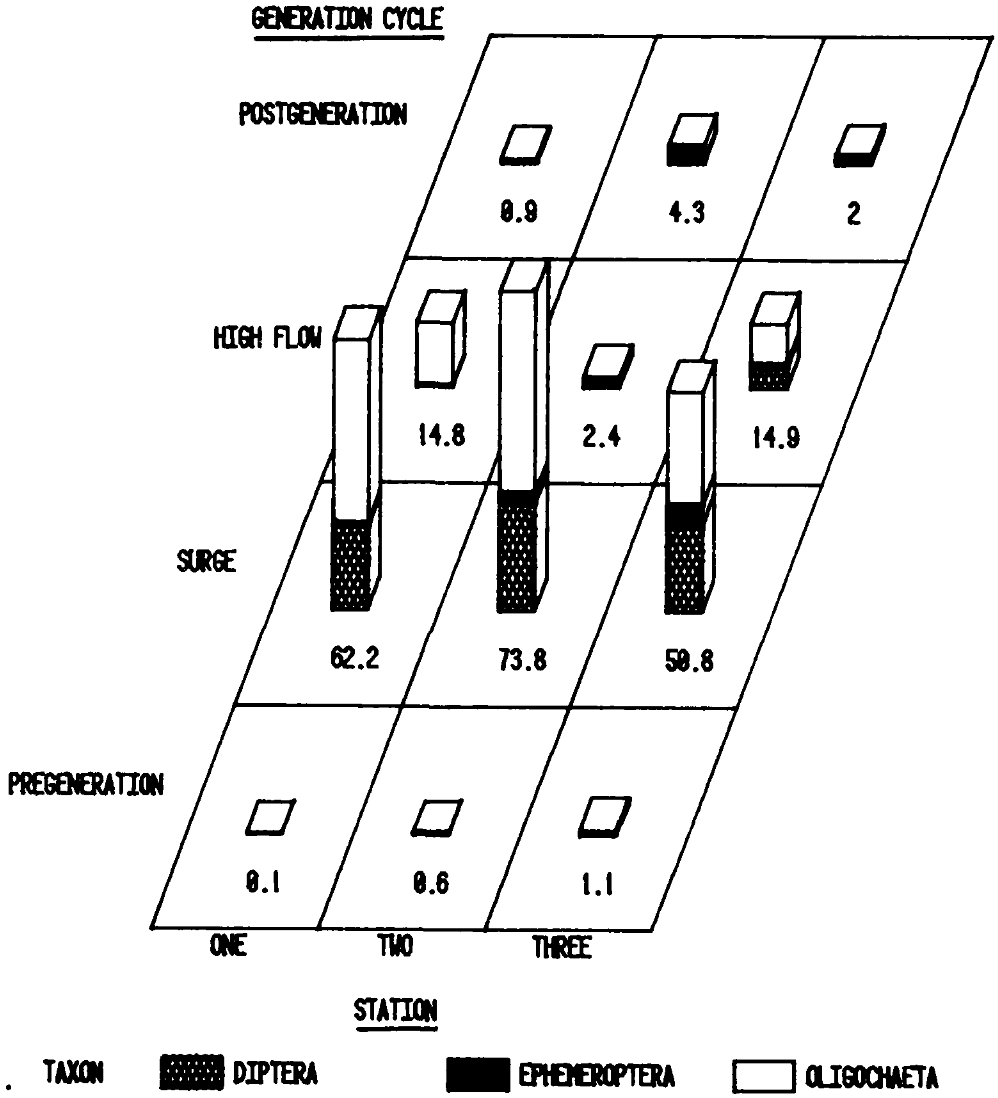


Figure 10. Estimated densities (number m^{-3}) of major taxonomic groups of tailwater benthos over a generation cycle. Drift density is dominated by Oligochaeta and Diptera

from 932×10^6 to 1724×10^6 individuals (Figure 11) and from 11.7 to 13.1 kg (Figure 12). Both number and weight of drift are greatest during high flow when the greatest volume of water is released. Note that benthic forms are more important than reservoir invertebrates by weight than by numbers and that benthic invertebrate drift progressively increases downstream (Figures 9 and 11). The degree to which benthic organisms entering the water column at upstream stations are carried into successive downstream sites is unknown. Reported values underestimate actual levels since smaller invertebrates may escape through the 450-μm netting.

Drift studies during
weekend low flow release

28. Taxa present in the weekend drift samples were similar to those recorded during the weekday samples, but the relative abundance of major taxa was quite different (Figure 13). Reservoir invertebrates made up only 60 percent of the total weekend sample (versus over 90 percent of weekday samples), and as low as 34 percent during nonrelease periods. Oligochaeta made up only about 4 percent of the benthic drift with a majority of the transport occurring during the low flow release (versus 50 to 60 percent of the benthic drift in weekday samples). Diptera comprised about 22 percent of the weekend sample, in contrast to 30 to 36 percent for the weekday, and Ephemeroptera dominated the weekend samples (70 percent), while making up only 3 to 17 percent of the weekday samples.

29. The total transport of benthic and reservoir invertebrates, exclusive of Ephemeroptera, peaked during the release. Reservoir invertebrates reached their highest densities during the low flow release period (Figure 13). Drift of Ephemeroptera was greatest in the evening following the end of the release. Drift density during the initial surge was not determined, since drift was measured over the entire low flow release.

30. Total estimated 24-hr drift of reservoir forms was 5.54×10^6 individuals and 49.859 g (AFDW), substantially less than drift during a generation cycle. The total transport of benthic invertebrates over

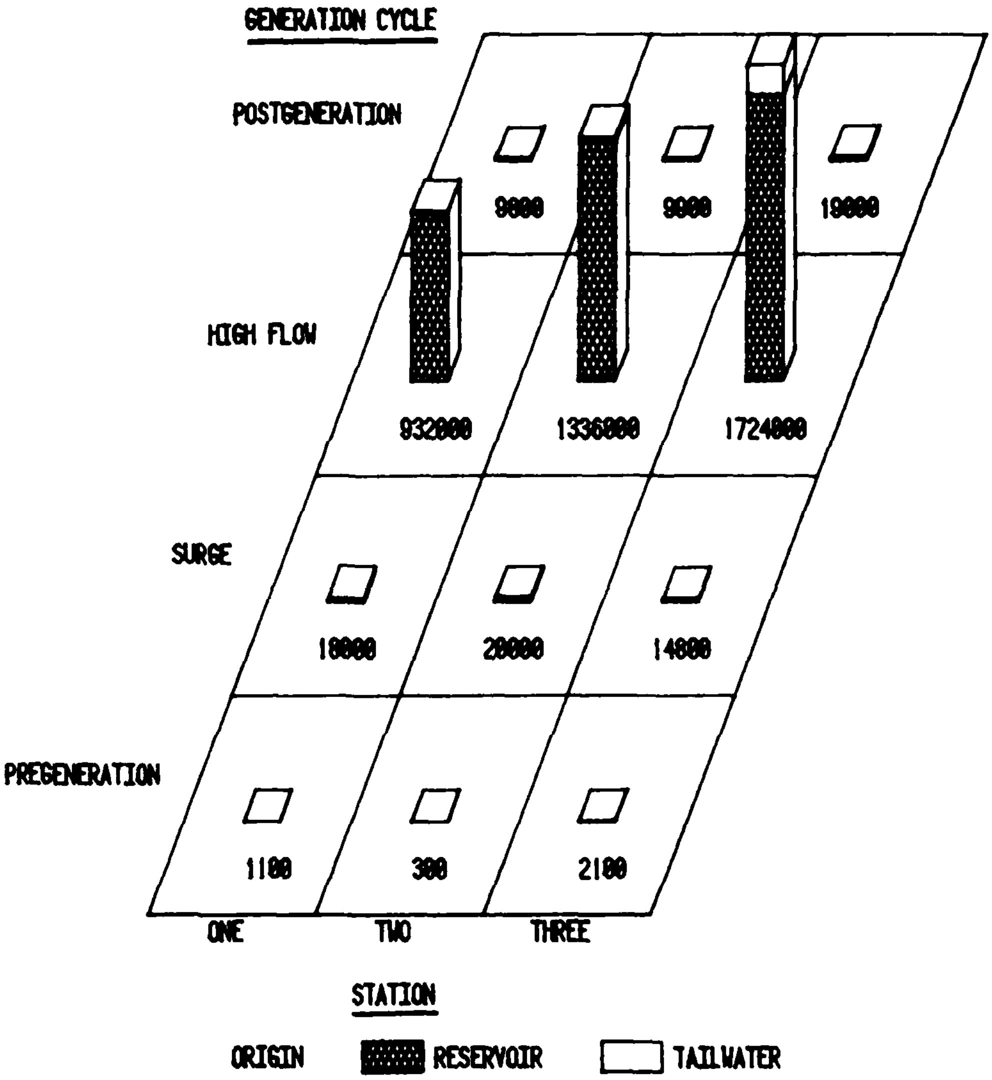


Figure 11. Estimated total numbers (number × 10^3 24 hr^{-1}) of reservoir and tailwater invertebrates passing through each station. Total drift number is dominated by the high flow period since it is both relatively long (6 hr) and large volumes of water are released

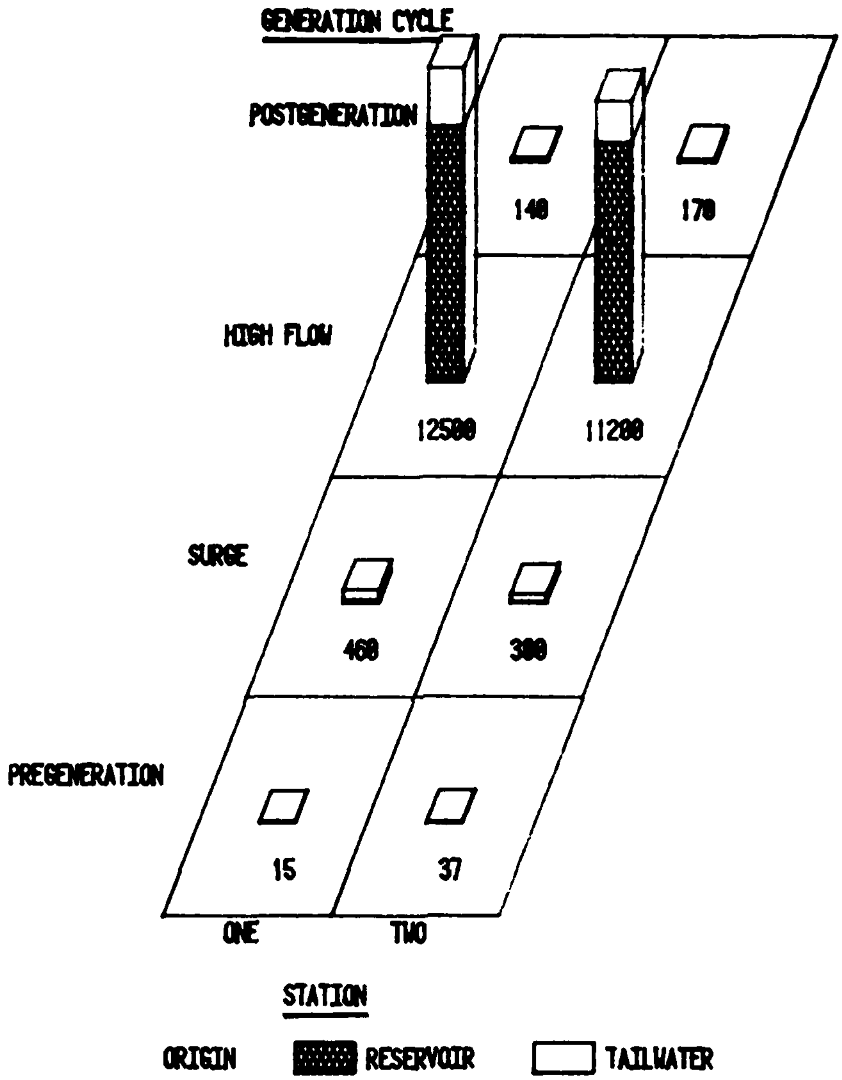


Figure 12. Estimated total weights (g AFDW) of reservoir and tailwater invertebrates passing through a cross section at each station over a generation cycle. As in Figure 11, totals are dominated by the high flow period. However, note the increased importance of tailwater benthos when weight is considered, reflecting the generally larger size of benthic invertebrates. Data from station 3 are unavailable

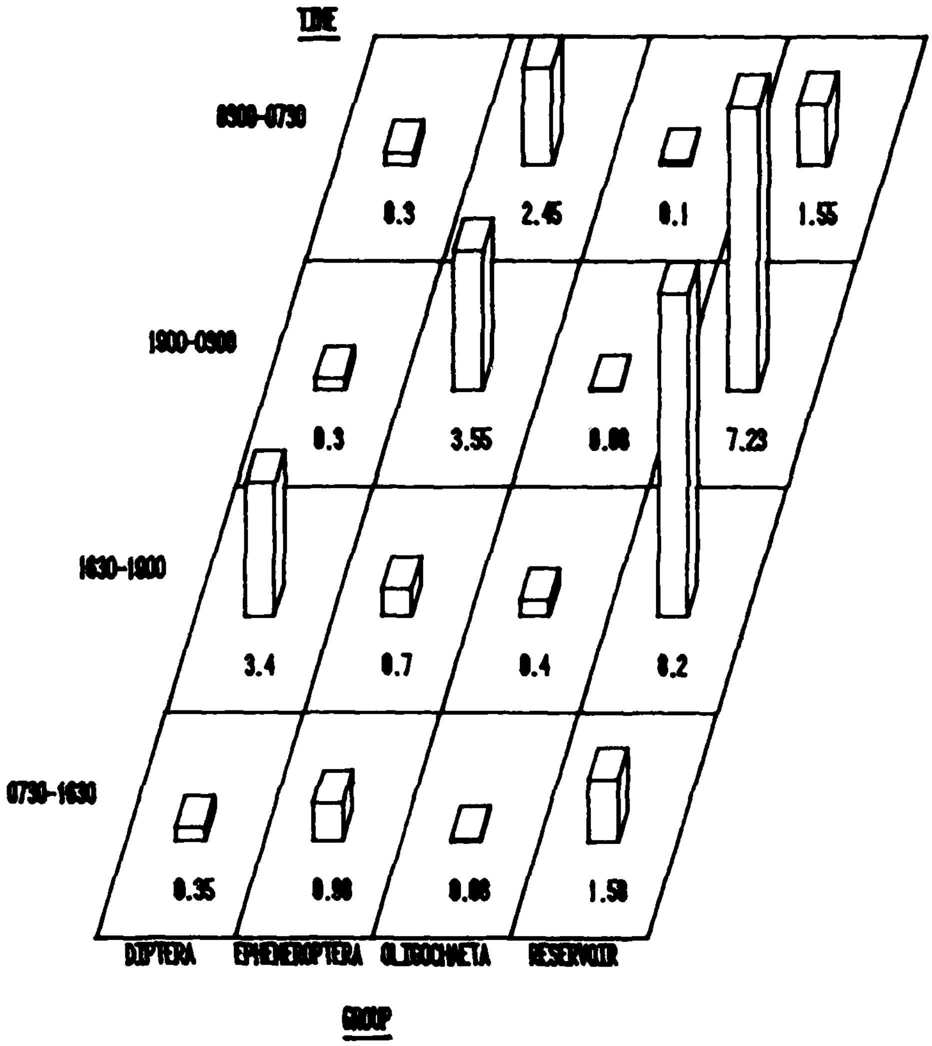


Figure 13. Estimated densities (number m^{-3}) of major groups of invertebrates collected in drift samples at station 2 of the Lake Hartwell tailwater over a 24-hr weekend period which included a short, low flow release for maintaining the tailwater trout fishery. Reservoir forms dominated during the release period (1630-1900) and the time period immediately following. Ephemeroptera exhibited nocturnal behavioral drift

24 hr was 3.36×10^6 individuals and 0.2 kg (AFDW), compared to 1.37×10^9 individuals and 11.7 kg (AFDW) for the station 2 cross section over a generation cycle (Figure 14).

Colonization studies

31. The mean number of organisms per artificial substrate sampler peaked at stations 1 and 2 after 19 days of exposure, but data from station 3 indicated a slower rate of colonization and no evidence of peaking even after 26 days (Figure 15). The number of organisms per substrate was highly variable between blocks at each station, especially at the 19- and 26-day recovery periods. Diptera, primarily Chironomidae, predominated and over time comprised a progressively greater proportion of the total invertebrates at all stations. Ephemeroptera and Oligochaeta made up a progressively smaller proportion of the total invertebrates with time at all stations. Taxa common at stations 2 and 3 but not found on station 1 blocks or represented by a single specimen included *Ephemerella* and *Stenomema* (Ephemeroptera), *Cheumatopsyche* (Trichoptera), *Hyallela* (Amphipoda), and *Physa* (Gastropoda). Hydracarina (water mites) and *Simulium* and *Antocha* (Diptera) were found at all stations but were more common at stations 2 and 3. Estimated biomass of benthic invertebrates and mass of organic material (primarily algae) attached to the artificial substrates (Figure 16) exhibited no observable trends.

POM Transport

32. Density and total transport of POM mirrored the movement of invertebrate drift through the tailwater (Figures 17 and 18). Note that POM densities increased with increasing distance from the project under all flow conditions; densities were greatest during the surge period; and most POM was in the less than 450-μm size class (Figure 17). POM samples collected in drift nets were comprised primarily of algal strands and mats.

33. The size distribution and abundance of POM were related to flow conditions and station location (Figure 17). Particles less than 80 mm changed only slightly under the different portions of the

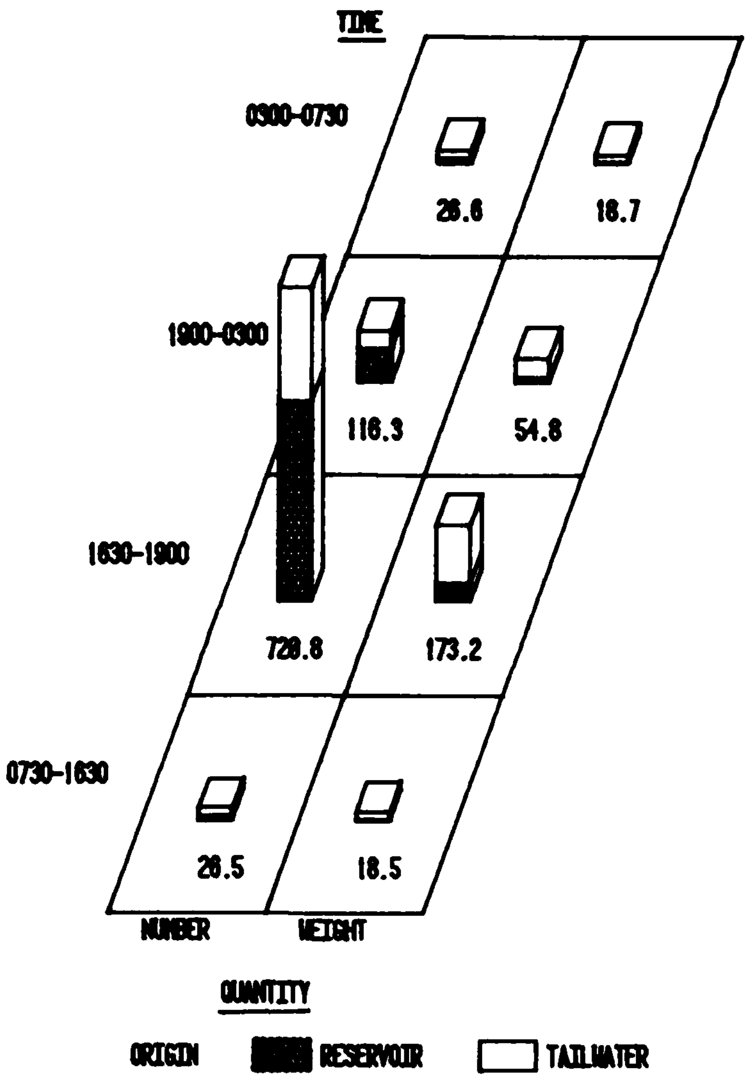


Figure 14. Estimates of the total number (× 10^4) and weight (g AFDW) of reservoir and benthic invertebrates drifting through a cross section at station 2 of the Lake Hartwell tailwater during a 24-hr weekend low flow release cycle, 21-22 July 1979

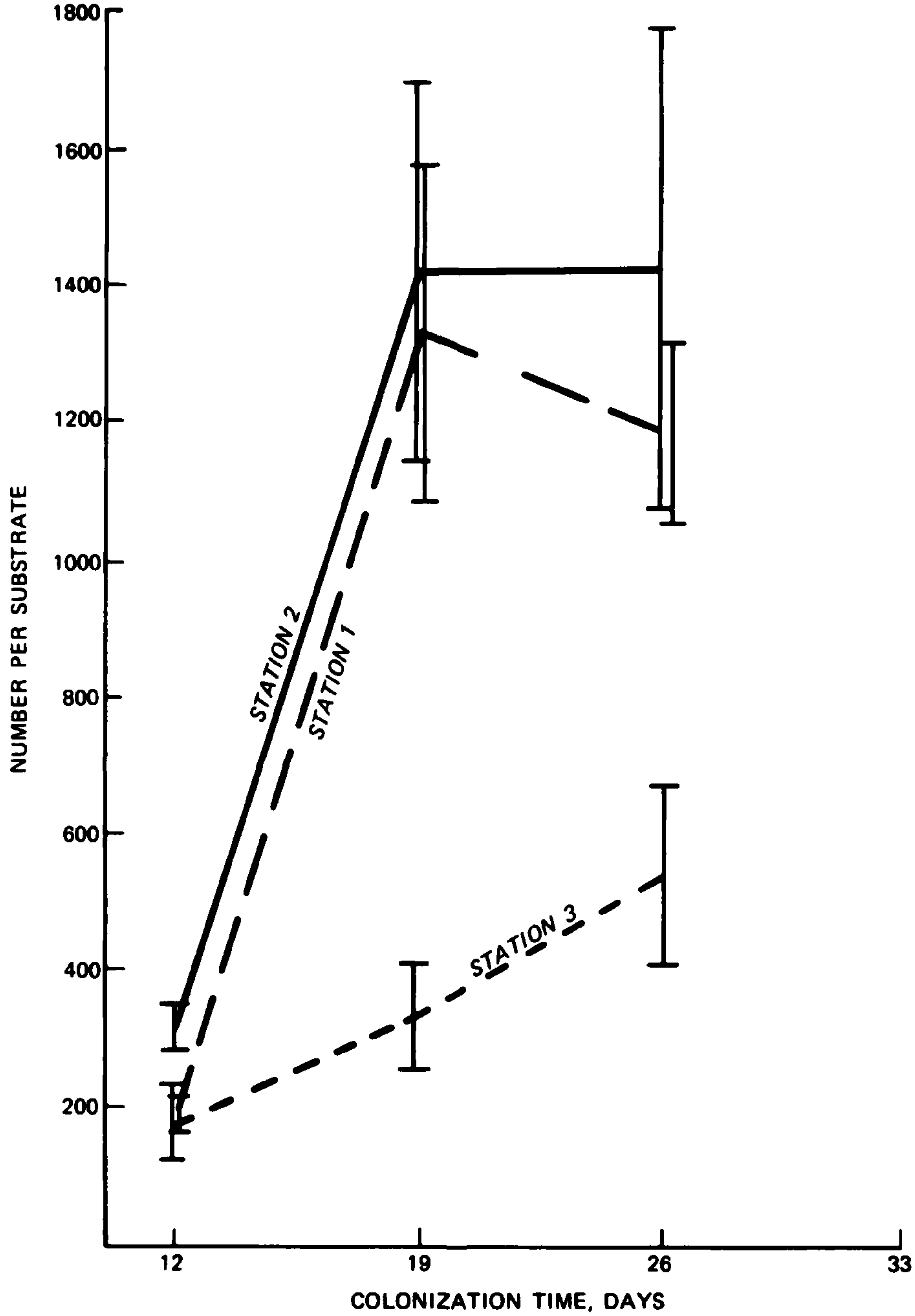


Figure 15. Mean colonization totals of invertebrates (number of organisms per substrate) at weekly intervals at three stations

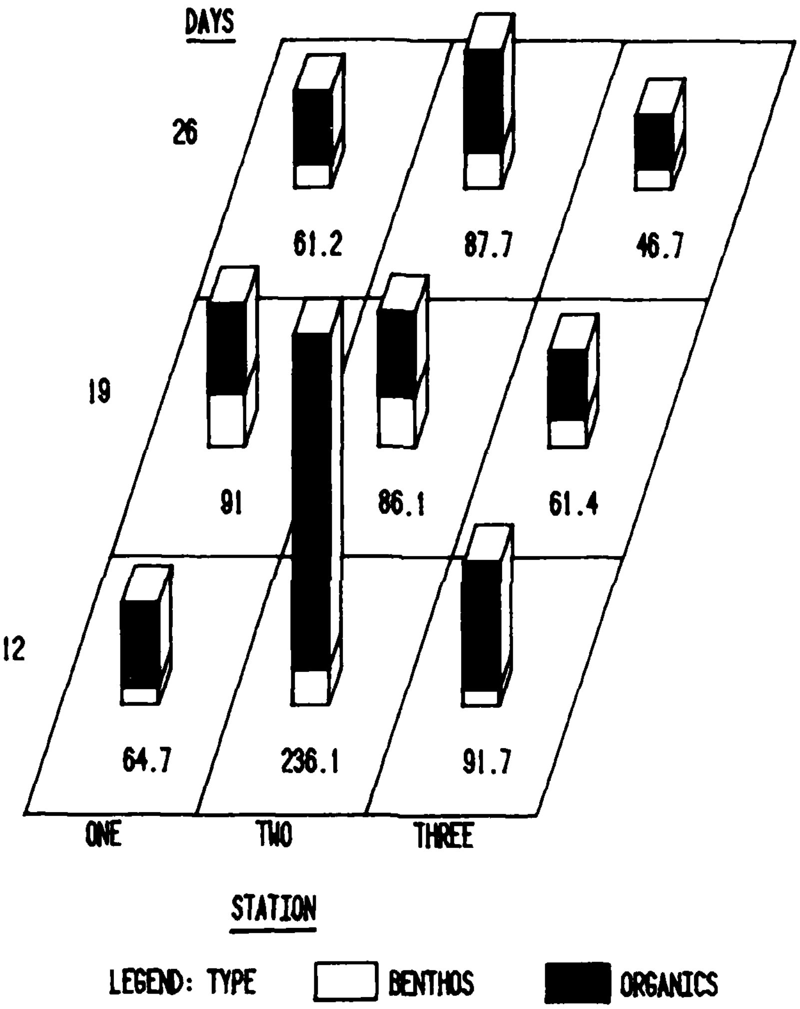


Figure 16. Mean colonization totals (mg AFDW per substrate) and mean total organic material (mg AFDW) at each station over time at the Lake Hartwell tailwater. Trends were not detected

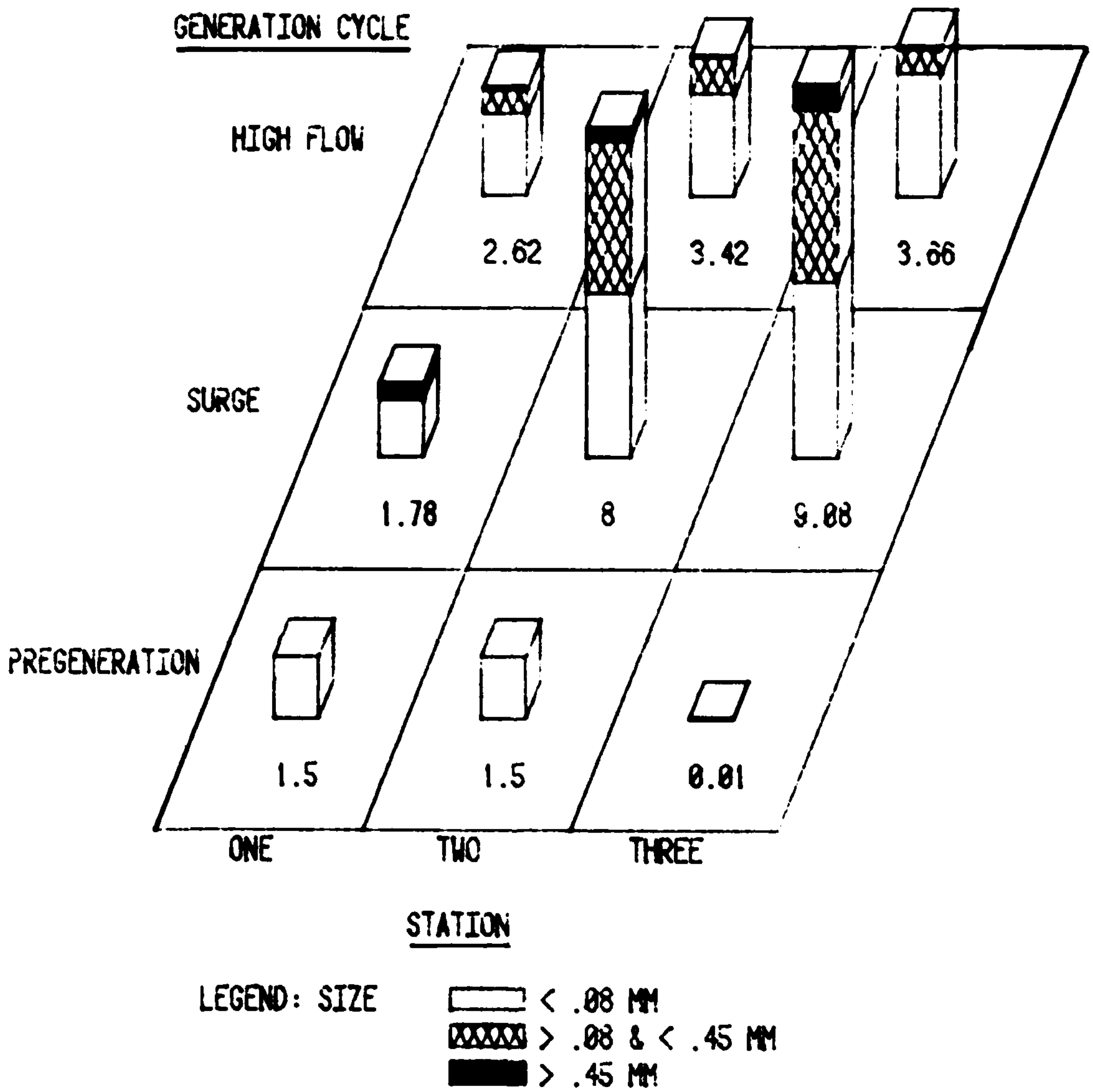


Figure 17. Densities (g AFDW m^{-3}) of POM collected in drift nets in the Lake Hartwell tailwater over a generation cycle. Note the increase in density with increased distance from the project and the dramatic increase in density of POM during the surge period. Data for the postgeneration period are unavailable

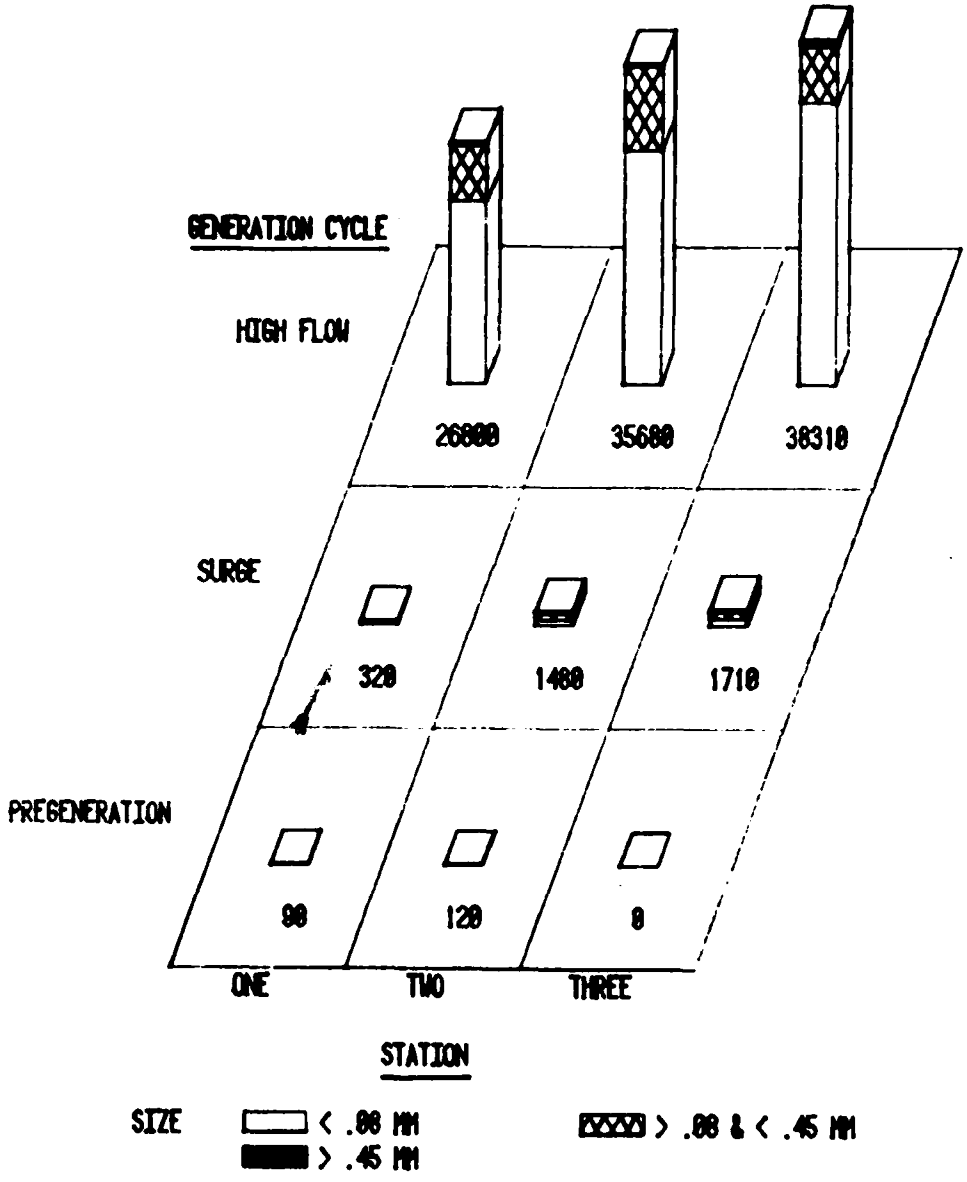


Figure 18. Estimated total mass (kg AFDW) of POM passing through a cross section at each station during different portions of a generation cycle on 12-13 July 1979. Note that totals are highest during the high flow period

generation cycle at station 1. POM greater than 80 μm at station 1 increased under high flow but not as rapidly as at the downstream stations. Large size particles were not detected at any station during the pregeneration period but increased dramatically during the surge period and then declined in density during high flow.

34. Estimated total transport of POM over 24 hr ranged from 27 to 40 kg (AFDW) (Figure 18). Almost 20 percent of the total transport occurred during the passage of the initial release surge, and most of the remainder was carried in the high flow immediately following the surge. Very small quantities of POM were transported during the pregeneration period. Postgeneration densities for 450 μm POM were not available. However, densities during this period were probably similar to those observed during the high flow period. Total transport of POM during the postgeneration period would, therefore, be of little importance since a relatively small quantity of water would be passing through the tailwater.

Chlorophyll Studies

35. Total chlorophyll-a transport at all stations was lowest during nongeneration periods (Figures 19 and 20). A marked peak in chlorophyll, well above levels within the reservoir, occurred at all river stations at the first pulse of release water. However, the duration of these high pulse concentrations may have been short, certainly less than 30 min. The bulk of total losses over a generation cycle probably occurred during the relatively long period (e.g. 5 to 7 hr) of sustained flows which follow the initial release surge. After maximum release flows had been reached, the concentration of chlorophyll dropped to levels only slightly above pregeneration conditions, but remained generally above reservoir levels. At all levels of discharge, more chlorophyll-a was associated with particles less than 80 μm than with particles between 80 and 420 μm.

36. Pheophytin is a natural degradation product of chlorophyll-a that normally increases in concentration with decreasing algal

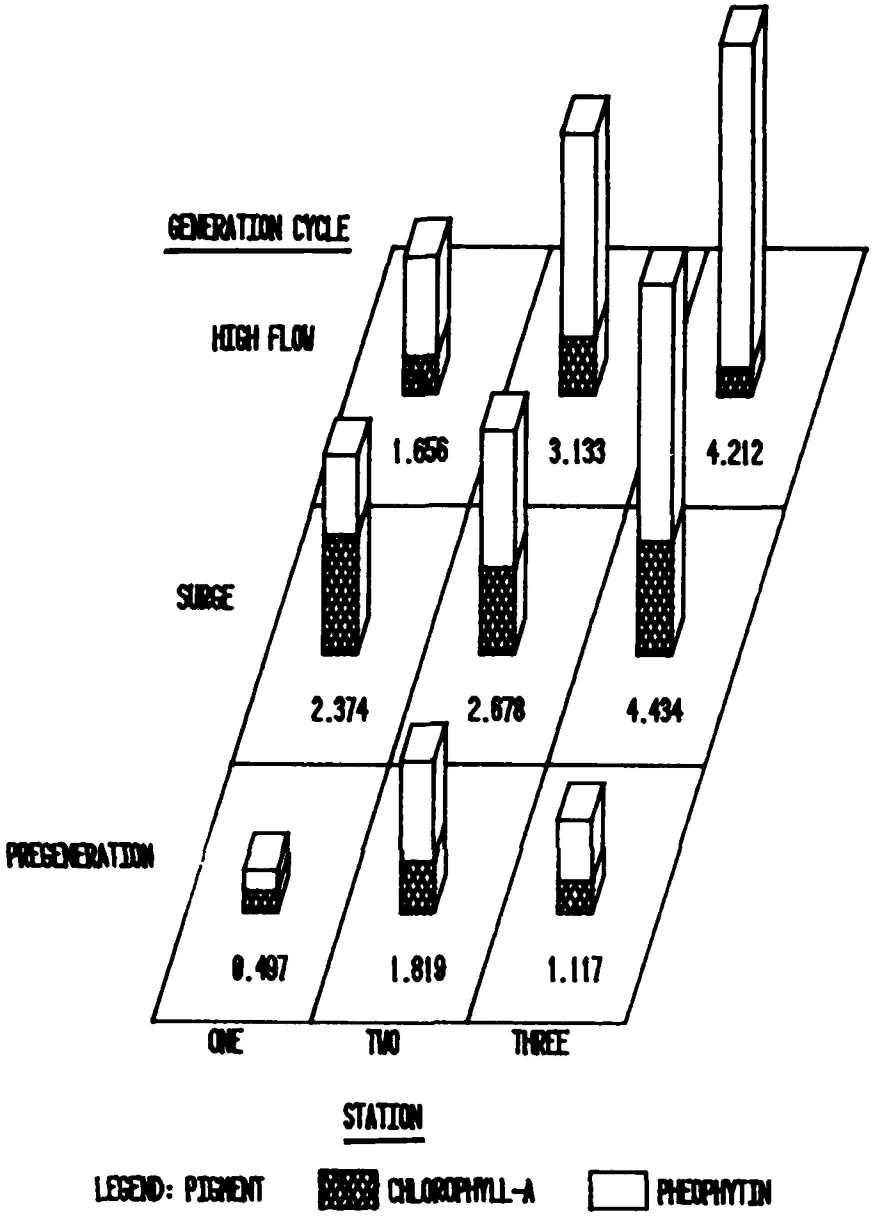
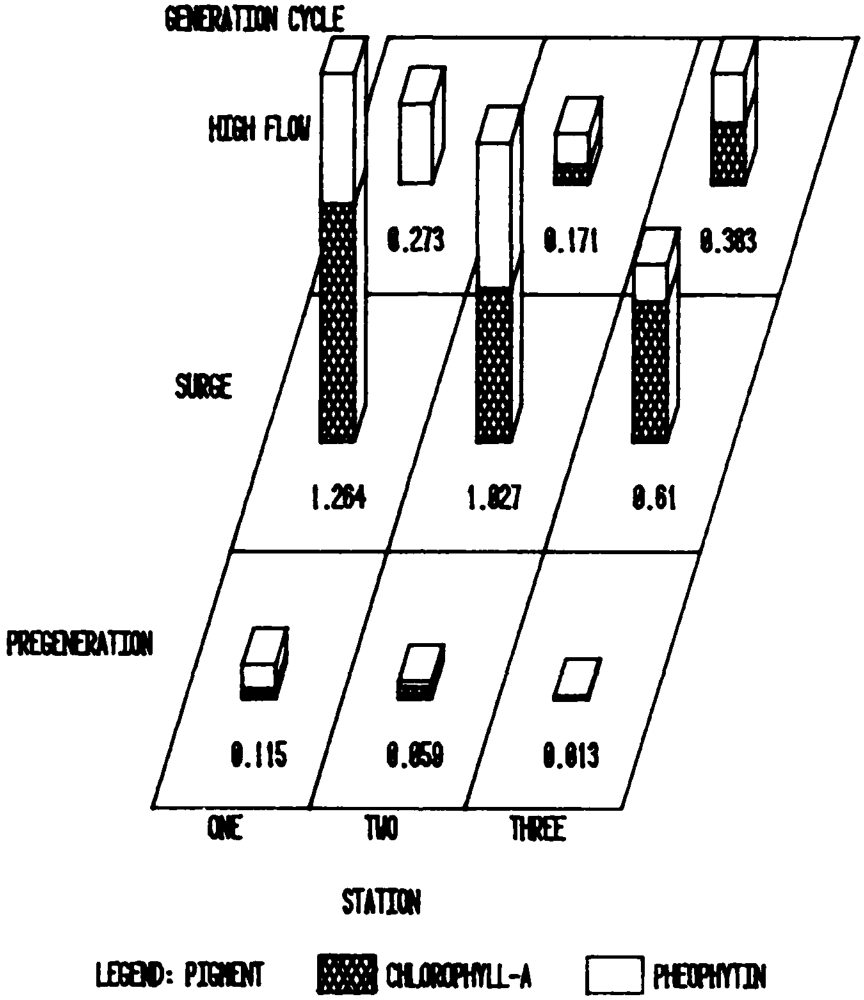


Figure 19. Estimated total pigment concentrations (mg m^{-3}) in <80-μm size classes in grab samples taken from the Lake Hartwell tailwater on 12 July 1979. Note both the increased downstream pigment concentrations and the increase in relative pheophytin. Reservoir pigment concentrations (total/viable) were 1.01/0.70, 0.87/0.34, and 0.70/0.13 mg pigment m^{-3} at depths of 20, 30, and 40 m, respectively



Figue 20. Total pigment concentrations (mg m^{3}) in >80-μm but <450-μm size class in grab samples from the Lake Hartwell tailwater over portions of a generation cycle on 12 July 1979. Note the decreased downstream pigment concentrations in the "surge" period and the decrease in relative pheophytin concentration

physiological condition. Additionally, compounds commonly found in detritus and organic matter will absorb light like pheophytin. Therefore, the generally low chlorophyll/pheophytin ratios obtained for the tailwater samples (Figure 21c) may indicate that many of the cells were near senescence or that healthy cells were embedded in a substrate heavily laden with detritus.

37. Chlorophyll-a bearing cells released from Hartwell Reservoir would be expected to suffer rapid losses within the tailwater due to physical damage and removal by filter feeders. No consistent pattern of chlorophyll-a concentration was apparent for sites increasingly distant from the dam.

Survey of Attached Plants

38. The unexpected diversity of the algal flora and heterogeneity of the habitat during the July sample precluded successful quantification of either relative abundance or biomass. Qualitative results from the 13 July sample effort may be found in Appendix A. Although the November sample was collected several months after the other portions of this study were completed, the similarity of the species composition indicated that the November sample may generally describe summer conditions. However, caution must be exercised when using these data in conjunction with other portions of this study.

39. Within the 36 taxa identified during the fall study, there was a tendency toward dominance by the blue-green algae (Table 2, Figure 21). Relative abundances also reflected this trend on a per species basis. It should be noted that the filamentous genera *Lyngbya*, *Oscillatoria*, and *Phormidium* formed the bulk of periphyton biomass.

40. Several taxa dominated the diatom and green algae communities sampled (Table 2) and *Achnanthes microcephala* was clearly the most dominant. This taxon is tolerant of a pH range from 6.4 to 8.5 with an optimum in the range of 6.4 to 6.6 (Lowe 1974) and is generally indicative of permanent aerobic conditions in weakly acidic waters (Cholnoky 1968). *Achnanthes microcephala* was not dominant in the summer

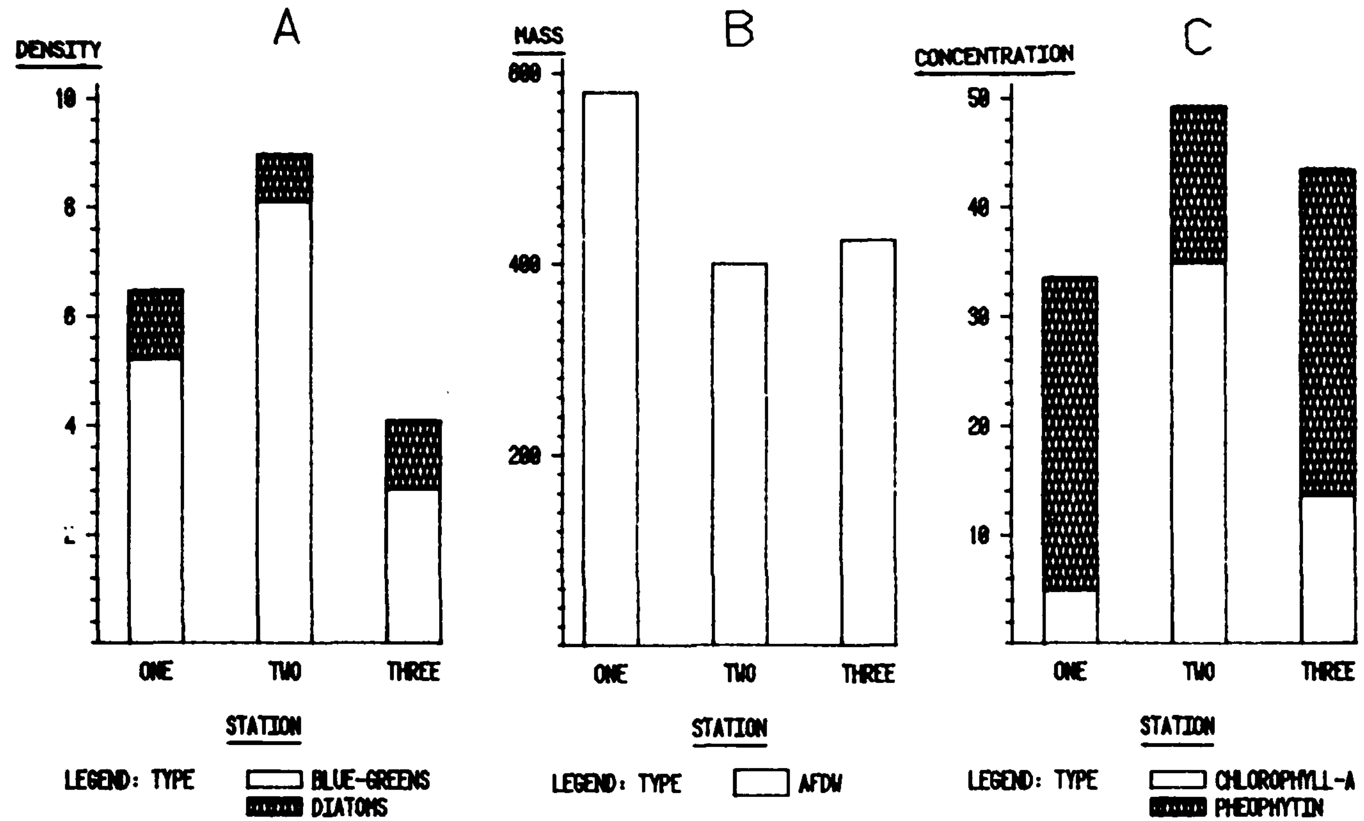


Figure 21. Results from November 1979 algal survey at three stations in the Lake Hartwell tailwater. A: Number of attached algal cells (× 10^6 cm^2). No station trends were observed. In general, blue-green algae were more dominant than diatoms. B: Weights (g AFDW m^{-2}) of attached algae. No station trends were observed. C: Chlorophyll concentrations (g m^{-2}) exhibited no discernable pattern

collection, probably reflecting low oxygen concentrations of deep releases from Lake Hartwell. Other common diatom taxa collected included *Cymbella microcephala*, *Anomoeoneis serians*, and *Navicula radiosa*. These cosmopolitan species were also present in the summer sample.

PART IV: DISCUSSION

41. This report focuses on short-term impacts of peaking power operation on scour, movement, and transport of benthos and POM over a 24-hr period since this information is not readily available in the literature. Generic impacts of peaking hydropower operation are well documented in the literature and include work on erosion and sedimentation (Ariathurai 1980; Beschta, Jackson, and Knoop 1981), minimum low flow releases (International Engineering Company, Inc. 1981; Loar and Sale 1981), water level fluctuations (Hildebrand et al. 1980b; Ploskey 1981, 1982), changes in oxygen concentrations (Cada et al. 1982), gas supersaturation (American Fisheries Society 1980), fish health (Dudley and Golden 1974; Grizzle 1981), fish entrainment and turbine mortality (Turbak, Reichle, and Shriner 1981), and design considerations for fish passage (Hildebrand et al. 1980a). General references or reviews on impacts of peaking power generation include Task Committee on Environmental Effects of Hydraulic Structures (1978), Tennessee Valley Authority (1978), and Walburg et al. (1981).

Invertebrate Studies

Generation cycle studies

42. The results of the field study demonstrate that peaking power operation over a 24-hr period has substantial impacts on the movement and transport of reservoir (primarily zooplankton and *Chaoborus*) and stream invertebrates within the tailwater. Moreover, the timing of movement of the numerically dominant reservoir-originated invertebrates differs substantially from the movement of tailwater benthic forms. A similar dominance by microcrustaceans from the reservoir was observed downstream from Cow Green Dam in Wales (Armitage 1977). Although benthic invertebrate drift is not numerically important (about 5 percent of total animals collected), it does compose approximately 20 percent of the total weight of animals collected because of the larger size of benthic forms. The size and density of prey items partially determine the

energy cost of foraging (Kerr 1971). Availability of large, abundant prey items will result in increased fish growth (Morrissy 1967; Campbell 1979). The larger, benthic invertebrates may be of importance to the tailwater fishery since their greater size suggests that they are better quality fish food (Kerr 1971; Pidgeon 1981). The surge period may, therefore, be of importance to tailwater fish since density of benthic invertebrates is greatest during this time period. The feeding behavior of fish during the surge period requires further investigation.

43. Transport of reservoir invertebrates in the drift appears to depend upon the quantity of water released. Proportionally greater numbers of zooplankton were entrained with increasing generation releases and peak densities occurred with maximum releases. Although there can be some degree of selective elimination of zooplankton as they are transported through the tailwater (Hynes 1970), the drift data generally did not reflect such losses (i.e., density of reservoir invertebrates did not differ significantly between stations) except during the postgeneration period when densities declined progressively downstream. The large volume of releases and concomitant high velocity of flows in the tailwater may have caused selective elimination to occur over much greater distances than were sampled in the Lake Hartwell tailwater. The drift pattern of *Chaoborus* and zooplankton (Figure 9) may also have been influenced by vertical migration of these organisms through the withdrawal plume during generation.

44. The dynamics of benthic drift in the tailwater appear to be largely catastrophic in nature in that movement is similar to that observed during naturally occurring floods. The magnitude of catastrophic (nonbehavioral) drift of tailwater invertebrates is determined by the interaction of scour forces, substrate composition, density of benthic populations, and behavioral response. Scour force is a function of all the factors acting to disturb the substrate or irritate and entrain benthic organisms, including water velocity changes, water level fluctuations, and water quality alterations. Benthic invertebrate drift density exhibited a substantial increase during the initial surge of water associated with peaking power operation, suggesting that

the combination of scour forces and the probability of exposure to these forces was particularly great during this period of the generation cycle. Brooker and Hemsworth (1978) observed a similar increase in drift density with a peak occurring with the passage of the initial surge during a 2-day release from a reservoir in Wales. The catastrophic nature of drift in the Lake Hartwell tailwater is further indicated by high densities of Oligochaeta and Chironomidae during the surge and high flow periods. These groups are found in low concentration during nongeneration periods.

45. Although the maximum density of drifting invertebrates occurred during the surge, the total number and weight was only about 10 percent of the transport during the high flow period since relatively little water was discharged during the short surge period. Consequently, the surge effect was of relatively little importance compared with total 24-hr transport of benthic invertebrates. The decline in benthic drift density after the initial surge in the Lake Hartwell tailwater was probably not the result of reduced scour force since discharge continued to rise after the surge. During the relatively long nongeneration (low flow) period, benthic invertebrates may disperse with respect to current direction to forage for food. The initial surge of water may sweep away all benthos that are not oriented to resist the increased flows. Also, benthic invertebrates may be capable of making themselves less susceptible to dislodgment, especially by downward movements into the substrate (Hynes 1974; Poole and Steward 1976). In contrast, Elliot (1967) and Anderson and Lehmkuhl (1968) reported increases in drift rate with increasing discharge but found virtually no change in drift density.

46. Drift levels of benthic invertebrates in the Lake Hartwell tailwater can be compared to drift in unregulated reaches of other river systems. However, any comparison of drift levels between systems will be biased due to differences in collection technique, time of collection, and net mesh size. Waters (1972) has suggested dividing the total number of benthic invertebrates drifting through a stream cross section in 24 hr by stream discharge in cubic metres per second as a

comparative index of "drift intensity" between streams. The index was 2.3×10^5, 3.34×10^5, and 12.92×10^5 for stations 1, 2, and 3, respectively, on the Lake Hartwell tailwater. Waters (1972) has reported values ranging from 3.0×10^6 to 15.0×10^6 for streams of a variety of sizes. Berner (1951) found a drift index of 2.6×10^6 for the lower Missouri River; Matter (1975) reported values ranging from 0.3 to 5.1×10^5 for the upper Mississippi River (Minnesota); and Bingham, Cobb, and Magoun (1980) reported an index of 2.44×10^6 for the lower Mississippi River (Mississippi). The drift indices for stations 1 and 2 in the Lake Hartwell tailwater are an order of magnitude lower than most reported values, except for the upper Mississippi River. The marked increase in the benthic drift index for station 3 is more similar to the other reported values, suggesting that drift rate at a particular station is at least partially determined by the cumulative amount of upstream habitat. Therefore, all other factors being equal, drift rate in the tailwater would increase with increasing distance from the dam. Similar results were obtained by Waters (1972) who observed that drift rate at any point in a stream is a function of processes occurring some distance upstream. He noted that drift passing over a unit area of the stream (usually 1 m^2) was one or two orders of magnitude greater than the standing crop of that area or a number equivalent to the entire estimated community from an area far upstream from the collection point. The effect of increased accumulated habitat area upstream from the drift samples is represented in Figure 22. Note that the benthic drift becomes proportionally greater than benthic standing crop with increasing distance downstream from the Lake Hartwell Dam. This evidence suggests that care must be exercised when comparing benthic drift in a tailwater with benthic drift in a riverine system or another tailwater since the downstream location of the drift samplers can be important. Additionally, this evidence suggests that the impacts of peaking power generation extend farther downstream than the 13.5 km sampled in this study.

Weekend low flow release

47. The impacts of the weekend low flow release on invertebrate drift were less than the impacts of a weekday generation cycle. Total

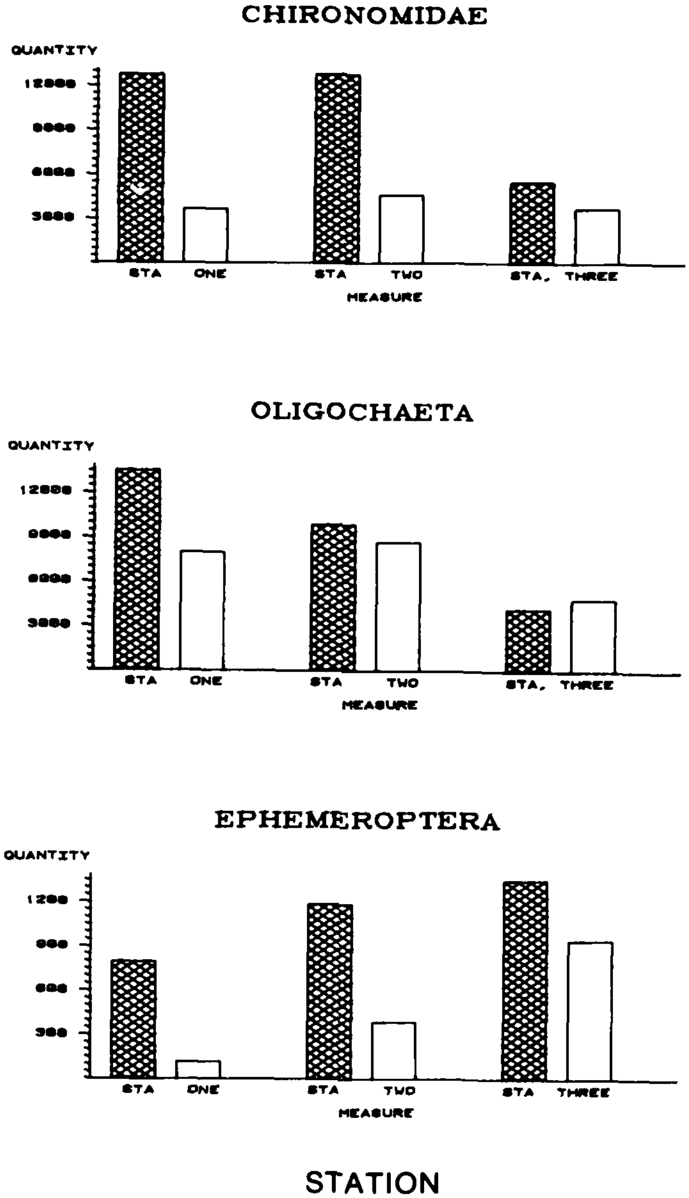


Figure 22. Relationship between mean standing crop of benthic invertebrates (No. m-2, cross-hatched bars) and drift (No. 1000 m3, unshaded bars) for different taxa in the Lake Hartwell tailwater. Note that drift becomes greater relative to standing crop at the downstream stations. Standing crop data obtained from Walburg et al. (1983) and U. S. Fish and Wildlife Service, Southeast Reservoir Investigations (unpublished data)

drift was substantially less than during a generation cycle. Additionally, the drift was dominated by benthic forms since the quantity of reservoir-originated forms is determined by the volume of releases. The effect of the initial surge was not determined since the nets were set out for the entire low flow release.

Colonization study

48. The results of the colonization study indicated that peaking hydropower operation does not preclude colonization of new or denuded substrates. Invertebrates common in the drift (Chironomidae and *Pseudocloeon*) were early and abundant colonizers on the artificial substrates. Chironomids were probably protected to some degree from the effects of scour and fluctuating water levels by their attached cases. Oligochaetes were not common colonizers probably because insufficient organic material had accumulated on the blocks (2 g m^{-2} on the blocks versus about 500 g m^{-2} AFDW on nearby bedrock).

Significance of drift losses

49. Significance of drift losses in the tailwater can be indirectly assessed by comparing drift at different discharge regimes to behavioral drift. Behavioral drift is a complex, incompletely understood phenomenon exhibited by some benthic invertebrates either in response to environmental conditions or as part of an endogenous rhythm. Waters (1964) and Dimond (1967) maintain that behavioral drift is largely a density-related response which regulates population levels relative to available resources. As such, behavioral drift should not be as extensive where continual catastrophic losses reduce benthic populations to levels well below the resource base. Ephemeroptera (primarily *Pseudocloeon*) exhibited a definite nocturnal increase in behavioral drift (density and rate) in the Lake Hartwell tailwater during nongeneration periods. Anderson and Lehmkuhl (1968) also found Ephemeroptera to retain diel periodicity in drift abundance despite catastrophic drift losses related to seasonal freshets. Brooker and Hemsworth (1978) and Armitage (1977) found much the same situation in streams subject to reservoir releases. This evidence suggests that some taxa (such as *Pseudocloeon*) are able to maintain substantial population levels

despite catastrophic drift losses either because of floods or reservoir releases. However, to suggest that production of a single taxon exceeds local resources despite scouring does not imply that an alternative release regime would have no impact on overall diversity and production of tailwater invertebrates. The preceding argument is not valid if behavioral drift is part of an endogenous rhythm that occurs irrespective of resource level.

50. Drift losses from the Lake Hartwell tailwater were compared to an estimate of total benthic standing crop. Data for this calculation were obtained from Walburg et al. (1983) and Southeast Reservoir Investigations, U. S. Fish and Wildlife Service (unpublished data). Benthic drift loss from the tailwater was estimated as the total benthic drift passing through a cross section over 24 hr at station 3. Calculated drift loss was estimated at 1.68×10^{8} organisms, whereas, calculated total benthic standing crop was estimated at 3.8×10^{10} organisms. Therefore, drift losses caused predominantly by peaking power generation over 24 hr in July at Lake Hartwell tailwater were approximately 0.5 percent of the estimated standing crop. A daily loss of 0.5 percent extrapolated to 1 month represents less than a 14 percent reduction in standing crop. A loss of this size can probably be counterbalanced by reproduction. Some macroinvertebrates can complete an entire life cycle in this time period. The degree to which this value changes with season is unknown. Additionally, the relatively small number of drift and benthic samplers render these values, at best, a rough approximation of actual percentage loss. Species that may suffer catastrophic drift losses exceeding their reproductive capacity would have been eliminated from the tailwater long before this study began.

Transport of Organic Matter

POM

51. This field investigation demonstrated that transport and redistribution of POM were substantially affected by 24-hr peaking

power generation. Changes in POM densities and totals among time periods were similar to those observed with benthic drift densities. The greatest densities occurred during the surge, especially among larger size classes, suggesting that scour of periphyton and macrophytes does occur. Greatest total transport occurred during the high flow period.

52. Peaking power generation also alters the composition of POM in the tailwater. POM that occurs in abundance in natural streams is largely replaced by other types in tailwaters. The reservoir acts as a particle trap and retains up to 90 percent of the POM carried in from the watershed (Lind 1971; Armitage 1977; Simons 1979). The fluctuations in water depth and velocity accompanying releases may be envisioned as regularly occurring floods because they flush POM from tailwater reaches like natural floods (Ward 1976). However, generation releases occur far more frequently than natural floods and, as a consequence, large-particle POM, such as leaves, bark, and twigs, do not accumulate in the tailwater. The reservoir exports plankton to the tailwater and the clear, nutrient-rich releases from the hypolimnion of stratified reservoirs foster the development of luxuriant growths of periphyton and attached macrophytes.

53. Substantial amounts of POM were transported out of the Lake Hartwell tailwater. The increasing density of POM moving downstream from the dam suggests that substantial amounts of POM are produced within the tailwater, especially since qualitative observation indicated that much of the POM collected from the water column consisted of fragmented periphytic algal mats and aquatic macrophytes. The virtual absence of large POM shredders and the predominance of periphyton scrapers in the benthos also indicate that large-particle POM inputs are not important energy sources within the stream reach and time period sampled.

Chlorophyll

54. In addition to monitoring the movement of POM by direct measurement, POM movement can be indirectly traced by following changes in chlorophyll-a and pheophytin concentrations in the tailwater. The two size classes of particles for which chlorophyll and pheophytin were determined (<80 μm, and >80 μm but <450 μm) reacted differently over the

generation cycle. The reasons for two different trends are unknown and, therefore, the significance cannot be estimated. Total pigment concentration in the releases increased with distance downstream from the project, suggesting that transport, as estimated by chlorophyll, may be partially determined by the amount of upstream area colonized by periphyton.

Significance

55. The significance of POM losses in the tailwater was assessed by comparing an estimate of standing crop of organic matter for the 12.1 km immediately downstream from the reservoir with the total POM transport through station 3 over 24 hr. Total transport of POM past station 3 was about 40,000 kg. Total estimated POM on the tailwater substrate was approximately 9.0×10^8 kg. POM transport past station 3 was less than 0.01 percent of total substrate POM. The relatively small percentage of POM transport results from the previous export of easily transportable material, so that only matter resistant to scour remains in the tailwater. Therefore, scour probably determines the distribution of particulate matter in the tailwater, but does not remove a substantial portion of the remaining material during a generation cycle. Care must be exercised when extrapolating this information, either to other time periods since maximum POM movement in the tailwater may be determined by a seasonal event such as reservoir turnover, or to other projects since standing crop of POM will be determined by water quality of the releases, a predominantly site-specific factor. Similar results were obtained using total plant pigment (chlorophyll-a and pheophytin). Total periphyton pigment on the Hartwell tailwater substrate was roughly estimated as 1.0×10^5 kg and total pigment passing through a cross section at station 3 over 24 hr was estimated as 40 kg. Approximately 0.04 percent of the total algal biomass, as indicated by pigment concentration, was flushed out with each generation cycle.

56. Surge affected POM less than benthos. Less than 5 percent of total POM transport occurred during the surge period. This evidence suggests that scour of POM from the tailwater substrate during start-up was negligible compared to total POM transport.

57. The dynamics of POM movement in the Lake Hartwell tailwater are at least partially reflected in the composition of the benthic community. The presence of an upstream reservoir that retains POM washed in from the watershed plus the regular periods of high flow prevents the accumulation of large-particle organic material. These effects are evidenced by the infrequent occurrence of leaf and twig dams or packs in the tailwater. Benthic shredders, normally feeding on and living in accumulations of large particulate organic matter, find little available habitat. For example, the Plecoptera, with many taxa known to be shredders, were relatively uncommon and those few present were dominated by predaceous genera. However, the altered regime in the tailwater may also limit this group (Lehmkuhl 1972). Filter-feeding organisms were uncommon in the Hartwell tailwater, except for a few hydropsychid and simulid larvae, because the deep releases do not carry the quantity or quality of fine particle materials which normally support large populations of filter-feeding invertebrates below shallow release reservoirs (Ward and Stanford 1979). The increased abundance downstream of particles <450 μm may explain the increased density of hydropsychid caddisflies at station 3. The highly fluctuating flows may also limit filter-feeding invertebrates by interfering with normal feeding behavior. In addition, reproduction and growth of filter-feeding invertebrates may be limited by altered water quality.

58. A variety of benthic invertebrates have found suitable living conditions in the Hartwell tailwater. Fine particulate detritus is probably supplemented by ingestion of periphyton by oligochaetes. The scrapers (primarily chironomids) are particularly well suited to exploit the abundant periphyton growing on the substrate, but were no more abundant than the oligochaetes. This suggests that some habitat feature other than food was strongly impacting scraper populations. Many of the tailwater invertebrates, especially the Diptera, may be exploited by fish. Pidgeon (1981) observed that gut contents of trout were related to the abundance and composition of tailwater benthos. These predators may also feed on zooplankton and *Chaoborus* entering the tailwater from the lake.

59. The differences between percent transport (transport/standing crop) for POM, plant pigment, and drift provide some insight into the functioning of the benthic community. The rock surfaces were encrusted with one to several layers of periphyton with substantial quantities of silt, organic debris, and detritus embedded within and between layers. This material harbored an abundance of oligochaetes, nematodes, and chironomids. The periphyton, attached macrophytes, and associated detritus appeared more resistant to high flows than the benthos.

60. The results of this study suggest that tailwaters downstream from deep release, peaking power projects export more organic matter than they receive from the reservoir. A substantial portion of the reservoir-originated invertebrates are swept downstream through the tailwater. Additionally, a portion of the organic matter produced within the tailwater is carried downstream with generation releases. The ultimate fate of this material is unknown. It may be utilized further downstream or in the next reservoir.

PART V: CONCLUSIONS

61. The results of this field investigation demonstrate that the composition and abundance of different types of food for benthic organisms downstream from a peaking hydropower project are quite different from that expected in a natural stream. The altered food base, in conjunction with modified chemical and physical conditions, provides habitat for a substantial benthic community, although less diverse and productive than tailwaters downstream from flood control projects (Walburg et al. 1983) or natural streams. Flows associated with peaking hydropower generation remove a relatively small proportion of the total in situ standing crop of POM, periphyton, and benthos from the tailwater over a generation cycle. However, the high flows probably prohibit the accumulation of large-particle organic material in the tailwater. The food base of the tailwater biota may be subsidized by zooplankton, *Chaoborus*, and larval fish from the reservoir.

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Table 1

Relative Abundance (percent) of Benthic Macroinvertebrate Taxa Collected in Drift Nets Within the Lake Hartwell Tailwater, July 1979

Taxa	Station 1	Station 2	Station 3
Oligochaeta*	65	48	50
Diptera			
Chironomidae**,†	30	29	34
Dolichopodidae	tr	--‡	--
Ephydridae	--	--	tr
Simuliidae	--	2	2
Tipulidae	--	tr	--
Ephemeroptera			
Pseudocloeon	3	17	7
Ephemerella	--	tr	2
Isonychia	--	tr	--
Stenonema	--	--	tr
Trichoptera††	1	1	1
Coleoptera			
Elmidae	tr	tr	tr
Odonata	--	--	tr
Amphipoda			
Hyalella	tr	tr	tr
Isopoda			
Asellus	--	--	tr
Hydracarina	--	tr	2
Nematoda	--	--	tr

Note: tr = trace.

* Predominantly Naididae (over 95 percent), followed by Lumbriculidae.

** Larvae and pupae.

† Predominantly *Cricotopus* and *Orthocladius* (over 95 percent of the Chironomidae), followed by a few other Orthocladiinae.

†† Predominantly *Hydroptila* (over 70 percent) followed by *Cheumatopsyche*.

‡ Not collected.

Table 2

Percent Composition of Periphyton Samples Collected in November for All Taxa (Each Value Is Mean of Four Replicates)

Taxon	Station 1	Station 2	Station 3
Blue-Greens:			
Anabaena	--	0.6	0.4
Anacystis	--	2.0	0.3
Arthrospira	--	0.4	2.8
Aphanocapsa cf. *elachista*	7.5	--	--
Aphanothece sp.	--	4.5	0.3
Aphanothece saxicola	13.5	--	--
Chroococcus	--	0.4	--
Lyngbya	--	30.8	31.0
Oscillatoria	20.7	32.9	22.5
Phormidium	35.3	12.5	5.7
Greens:			
Ankistrodesmus falcatus	0.2	0.1	0.3
Bulbochaete	--	0.9	--
Cladophora	--	3.0	2.4
Cosmarium	--	0.1	--
Micrasterias radiata	0.1	--	--
Mougeotia	0.1	1.0	--
Netrium	--	--	0.1
Pediastrum tetras	--	--	0.1
Radiofilum	2.0	--	--
Rhizoclonium	--	0.6	--
Scehedesmus	--	0.1	0.2
Staurastrum cf. *manfeldtii* var. *fluminense*	--	0.1	--
Diatoms:			
Achnanthes exigua	--	--	0.2
A. lanceolata	--	0.4	0.3
A. linearis	1.0	0.4	3.5
A. linearis f. *curta*	0.5	1.7	8.4
A. linearis v. *pusilla*	--	--	0.1
A. microcephala	7.4	3.3	15.4
A. minutissima	0.3	0.6	--

Taxon	Station 1	Station 2	Station 3
Anomoeneis serians var. *brachysira*	1.2	0.1	0.4
A. vitrea	0.1	--	0.1
Cocconeis placentula var. *lineata*	0.1	0.1	--
Cyclotella stelligera	0.3	0.1	0.1
Cymbella lunata	--	--	0.1
C. microcephala v. *crassa*	1.1	0.1	--
C. minuta	--	0.1	0.1
Diploneis puella	0.1	--	P*
Eunotia zasuminensis	0.1	0.3	0.1
Fragilaria construens var. *binodis*	0.2	--	--
F. vaucheria	1.4	0.4	1.1
Frustulia rhomboides	--	0.2	--
F. rhomboides var. *capitata*	0.2	--	0.3
Gomphonema gracile	0.4	0.1	0.3
G. parvulum	0.9	0.5	0.5
G. tenellum	--	--	0.1
Hantzschia amphioxys	0.1	--	--
Melosira distans	0.8	--	P
M. granulata	0.1	--	0.1
Navicula mutica var. *tropica*	--	0.1	0.9
N. radiosa	--	0.2	0.1
N. radiosa v. *parva*	1.3	1.0	P
N. sp.1	--	0.1	--
Neidium affine	--	0.1	--
Nitzschia dissipata	--	--	0.1
N. fonticola	--	0.2	0.3
Synedra acus	0.1	--	--
S. famelica	0.1	--	--
S. planktonica	0.1	--	--
S. rumpens var. *meneghiniana*	--	--	0.6
S. socia	0.2	0.2	0.1
S. ulna	0.3	--	--
Tabellaria fenestrata	0.4	P	0.7
T. flocculosa	0.3	--	P

* Denotes uncounted presence.

APPENDIX A: PHYCOLOGICAL SURVEY OF THE UPPER SAVANNAH RIVER*

Taxon	Station 1	G. C.**	Station 2	Station 3
CYANOPHYTA (Blue-greens)				
Lyngbya birgei	P	P	P	P
Oscillatoria spp.	P	P	P	P
CHLOROPHYTA (Greens)				
Ulothrix spp.	P	P	P	P
Stilgeoclonium subsecundum	A	P	A	P
Pediastrum duplex	P	A	P	A
Scenedesmus quadricauda	P	A	P	A
Closterium ralfsii	A	P	P	A
Cosmarium botrytis	A	P	P	P
Nitella tenuissima	P	A	P	P
Micrasterias sp.	A	P	P	P
Oedogonium spp.	P	P	P	P
Coleochaete spp.	A	A	P	P
Ankistrodesmus falcatus	P	A	A	P
Staurastrum sp.	P	A	P	P
Mougeotia sp.	P	P	P	P
CHRYSOPHYTA (Yellow-greens)				
Achnanthes exigua	A	A	A	P
A. lanceolata	A	P	P	A
A. lanceolata var. *dubia*	A	A	P	P
A. Levanderi	P	P	A	A
A. linearis f. curta	P	A	P	P
A. linearis var. *pusilla*	P	A	A	A
A. microcephala	P	P	P	P
A. minutissima	P	P	P	P
A. sp.	A	A	A	P
Anomoneis serians var. *brachysira*	P	P	P	A
A. vitrea	P	A	P	P
Asterionella formosa	P	A	P	P
Cocconeis placentula	A	P	P	P
C. placentula var. *linearis*	A	P	A	P
Cyclotella meneghiniana	A	A	A	P
C. stelligera	P	P	P	P
Cymbella laevis	P	P	P	P
C. lunata	P	A	P	A
C. microcephala	P	P	P	P
C. minuta var. *silesiaca*	P	P	P	P
C. triangulum	A	A	P	A
C. tumida	P	P	P	P
Denticula tenuis	P	A	A	A
Diploneis puella	A	P	A	P

* 'P' denotes presence; 'A' denotes absence. (Sheet 1 of 3)
** Generostee Creek.

Taxon	Station 1	G. C.	Station 2	Station 3
Eunotia curvata	P	P	P	P
E. curvata var. *capitata*	A	A	P	A
E. formica	P	A	A	P
E. naegelii	P	A	A	A
E. quaternaria	A	A	P	A
E. vanheurckii	A	A	P	A
E. zasuminesis	P	A	A	P
Fragilaria sp.	A	P	A	P
F. vaucheria	A	A	A	P
F. crotonensis	P	A	P	A
Frustulia assymetrica	A	A	A	P
F. rhomboides	P	A	P	P
F. rhomboides var. *capitata*	A	A	P	P
F. rhomboides var. *crassinervia*	P	P	P	P
F. rhomboides var. *saxonica*	A	A	P	A
F. vulgaris	P	P	P	P
Gomphonema acuminatum	P	A	P	P
G. gracile	P	A	P	A
G. helveticum	A	A	A	P
G. subclavatum var. *mexicanum*	P	P	A	P
G. parvulum	P	P	P	P
G. subtile	A	A	P	A
G. tenellum	A	P	P	P
G. truncatum var. *capitatum*	A	A	P	A
G. truncatum var. *turgidum*	P	A	A	A
G. ventricosum	A	A	P	A
Gyrosigma nodiferum	A	P	P	P
Melosira distans	P	P	P	P
M. granulata	P	P	P	P
M. varians	A	P	P	P
Meridion circulare	P	A	A	A
Navicula capitata	A	A	P	A
N. caroliniana	A	A	P	P
N. elginensis	A	P	A	A
N. exigua	A	A	P	P
N. hambergii	A	A	P	A
N. jaernfeltii	A	A	P	A
N. minima	A	A	A	P
N. mobiliensis	A	P	P	P
N. mutica	A	A	P	A
N. mutica var. *tropica*	A	P	A	P
N. notha	P	P	P	P
N. radiosa	A	P	A	A
N. radiosa var. *parva*	A	A	A	P
N. simula	A	A	P	A
N. spl cf. *halophila*	A	A	A	P
N. sp2	A	A	A	P

(Sheet 2 of 3)

Taxon	Station 1	G. C.	Station 2	Station 3
Nitzschia acicularis	P	P	P	P
N. amphibia	A	A	P	A
N. clausii	A	A	P	A
N. fonticola	P	P	A	A
N. gracilis	A	A	A	P
N. ignorata	A	A	A	P
N. lorenziana	P	A	P	A
N. palea	P	P	P	P
N. sp. cf. *parvula*	A	A	A	P
Rhizosolenia longiseta	P	A	A	A
Stauroneis nana	A	P	A	A
Surirella angustata	A	A	P	A
S. linearis	P	P	P	P
S. robusta	A	A	P	A
Synedra famelica	A	A	P	P
S. planktonica	P	A	P	P
S. pulchella	P	P	P	P
S. rumpens var. *meneqhiniana*	A	A	P	P
S. socia	P	A	P	A
S. ulna	P	P	P	P
S. ulna var. *oxyrhynchus*	A	A	P	A
Tabellaria fenestrata	P	P	P	P
T. flocculosa	P	P	P	P
Vaucheria sp.	A	A	A	P
RHODOPHYTA† (Red algae)				
Batrachospermum boryanum				
Lemanea australis				
Rhodochorton violaceum				

† Observed in previous collections from regions near Calhoun Falls.

(Sheet 3 of 3)

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Movement, transport, and scour of particulate organic matter and aquatic invertebrates downstream from a peaking hydropower project / by William Matter ... [et al.] (University of Arizona and Southeast Reservoir Investigations, National Reservoir Research Program, U.S. Fish and Wildlife Service). -- Vicksburg, Miss. : U.S. Army Engineer Waterways Experiment Station ; Springfield, Va. : available from NTIS, 1983.
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